Beach dynamics and recreational access changes on an earthquake-uplifted coast

Prepared for
Marlborough District Council
August 2020

Marine Ecology Research Group
University of Canterbury
Private Bag 4800
Christchurch 8140
ISBN 978-0-473-54390-7 (Print)
ISBN 978-0-473-54392-1 (Online)

For citation:
Orchard, S., Falconer, T., Fischman, H., Schiel, D. R. (2020). Beach dynamics and recreational access changes on an earthquake-uplifted coast. Report to the Marlborough District Council, 42pp. ISBN 978-0-473-54390-7 (Print), ISBN 978-0-473-54392-1 (Online). Available online from https://hdl.handle.net/10092/101043

For further information please contact:
shane.orchard@canterbury.ac.nz
Ph: +64 3 369 4141

Beach dynamics and recreational access changes on an earthquake-uplifted coast

Shane Orchard
Thomas Falconer
Hallie Fischman
David Schiel

Prepared for:

Marlborough District Council

August 2020

Marine Ecology Research Group
Earthquake Recovery Research Report

ISBN 978-0-473-54390-7 (Print)
ISBN 978-0-473-54392-1 (Online)

Cover image
View eastwards along the beach at Mussel Point with Cape Campbell in the distance
Photo: Shane Orchard

Abbreviations

MDC	Marlborough District City Council
DOC	Department of Conservation
ECPG	East Coast Protection Group
GIS	Geographic Information System
GPS	Global Positioning System
MBIE	Ministry of Business, Innovation and Employment
MDC	Marlborough District City Council
MPI	Ministry for Primary Industries
ORV	Off-Road Vehicle
QEII	Queen Elizabeth II
RECOVER	Reef Ecology and Coastal Values, Earthquake Recovery
RTK	Real-Time Kinematic
UAV	Unmanned Aerial Vehicle (drone)
UC	University of Canterbury

Contents

List of Figures

List of Tables

Executive summary

This report responds to a request from Marlborough District Council (MDC) for information on the coastal environment, with a particular focus on supporting the development of a bylaw to address changes in recreational use patterns that have occurred since the Kaikōura earthquake. We present a selection of information from our earthquake recovery research that has a focus on understanding the impacts and ongoing processes of change. Major impacts of the natural disaster are associated with vertical uplift of the coastal environment, although ongoing erosion and deposition processes are also important.
In addition, interactions with human activities are important because they can exert strong influences on the reassembly of ecosystems which is a critical aspect of outcomes over the longer-term.

Earthquake uplift caused widespread mortality of many coastal habitats and species (e.g., algal assemblages) that are adapted to a relatively specific set of conditions, often associated with characteristic locations in relation to the tidal range. In uplifted areas the intertidal zone has moved seaward leading to a physical widening of many beaches. This has provided greater opportunity for off-road vehicle access to the coast and has become particularly noticeable at headlands and other natural barriers that were previously impassable at high tide.

Off-road vehicles pose threats to sensitive vegetation and wildlife unless appropriately managed. Achieving this is assisted by an understanding of the specific impacts of vehicle use, which in turn requires information on the location of sensitive areas. To ensure the best outcomes for earthquake recovery there is an urgent need to assess and respond to the new spatial patterns, and to make plans to avoid conflicts where possible.

In our RECOVER (Reef Ecology and Coastal Values, Earthquake Recovery) project funded by the Ministry of Business, Innovation and Employment (MBIE) and supported by the Ministry for Primary Industries (MPI) we are collecting information on important conservation values and activities. Although research is continuing, this report provides findings that include mapping of indigenous dune system remnants, recruitment of the indigenous sand-binders spinifex (*Spinifex sericeus*) and pīngao (*Ficinia spiralis*) on uplifted beaches, distribution of red katipō (*Latrodectus katipo*) within earthquake-affected dune systems, distribution of banded dotterel / pohowera (*Charadrius bicinctus bicinctus*) nesting pairs to determine important areas, and spatial overlaps with vehicle tracking measurements along the coast.

Take-away messages

Based on the information collected to date, key findings include:

I. There is strong evidence for the recent decline of pīngao in this area that should be of concern to coastal managers given its conservation status as an ‘at risk – declining’ species and as a Ngāi Tahu taonga species. The overall pattern includes an apparent lack of recruitment to replace old-dune pīngao remnants that are under threat from ongoing environmental change.

II. There is a unique opportunity to help re-establish pīngao and spinifex dune ecosystems through a strategic restoration approach that takes advantage of the uplifted beaches.

III. To assist recovery processes and opportunities, there is a need to avoid vehicle damage to existing dune faces and new dune establishment zones (which are close to the new high tide mark), particularly where spinifex and/or pīngao are present. Similarly, there is a need to avoid disturbance to reef platforms which are only slowly recovering and are highly fragile in their current condition.

IV. On this coastline, the fore-dune face is an important area for katipō and should be a focus for conservation efforts, especially where sparse vegetation types such as pīngao and spinifex are present. This creates an additional reason for protecting newly developing fore-dunes and assisting the re-establishment of indigenous dune systems. There are also major differences in katipō densities along the coast in similar habitats due to unknown factors which require further research.

V. The distribution of banded dotterel nesting sites includes several well-defined hotspots (clusters of nesting sites in close proximity) that are priority areas for protection. The specific impacts of vehicle use in these areas require further work to determine, but there is considerable overlap with the current pattern of vehicle tracking. Effective measures are needed to control threats from vehicle movements through techniques such as spatial planning to ensure a separation between vehicles and nesting areas during the breeding season.

VI. Bringing together information from studies at a variety of scales is needed for a comprehensive understanding of earthquake change and to assess the merits of new management proposals. These needs will continue beyond the life of the RECOVER project since many important recovery processes are only just beginning (e.g., new dune establishment and algal assemblage recovery). At the same time, ongoing disturbances, including natural disasters and climate change, will continue to affect the coast and are important aspects for longer term monitoring.

1 Introduction

1.1 Earthquake recovery context

The moment magnitude (M_w) 7.8 Kaikōura earthquake was one of the most complex earthquakes recorded to date (Clark et al. 2017; Hamling et al. 2017a; Holden et al. 2017; Jiang et al. 2018). Energy was released over a period of approximately 90 seconds, resulting in multiple ruptures that propagated in a north-easterly direction and included offshore faults (Hamling et al. 2017a; Wallace et al. 2018; Xu et al. 2018). Many of the large surface-level slips (10 m or more) had not been previously mapped or were believed to be inactive faults (Hamling et al. 2017a). Variable degrees of coastal uplift (and some areas of subsidence) were recorded throughout the earthquake-affected area. The general pattern involved uplift of up to ~ 6 m on the Canterbury coast north of Kaikōura, and 0 – 2 m south of Kaikōura. Further north, the Marlborough coastline experienced uplift of up to ~ 3 m associated with rupture of the Needles fault in the area between Wharanui Beach and Marfells Beach (Clark et al. 2017; Hamling et al. 2017b; Jiang et al. 2018). Associated impacts in the coastal environment included widespread mortality of marine life along ca. 130 km of coastline, mainly associated with uplift effects (Alestra et al. 2019; Schiel et al. 2019; Schiel et al. 2018). Affected areas included the nearshore marine environment and adjacent terrestrial areas, all of which are home to characteristic habitats and resources on which people depend.

Recovery from natural disasters such as earthquakes highlights the importance of major step-change events in shaping the landscape. Responses in the natural environment add an important dimension to disaster recovery contexts (Orchard et al. 2020a; Orchard et al. 2020b). In this case, displacements effects have caused long-term changes to the structure of the environment that are important to recovery processes, in addition to their immediate effects. Due to the high level of interaction between people and the coast, the recovery of the natural environment and resources is also likely to be assisted by interventions of various kinds. Understanding the nature of impacts and direction of recovery trajectories enables the identification of opportunities and potential issues that arise from trade-offs between competing uses and needs.

1.2 Scope and objectives

This report responds to a request from Marlborough District Council (MDC) for information on the coastal environment, with a particular focus on supporting the development of a bylaw to address changes in recreational use patterns that have occurred since the Kaikōura earthquake. These changes were summarised in a recent MDC report (Marlborough District Council 2019b), and addressed in an issues-and-options paper prepared to support the bylaw process (Marlborough District Council 2019a). The objective of this report is to assist MDC and stakeholders in developing solutions for these needs and with a particular focus on the proposed bylaw and related-decision making within the wider community.

In the following sections, we present a selection of information from surveys completed within the University of Canterbury's (UC) RECOVER project. RECOVER (Reef Ecology and Coastal Values, Earthquake Recovery) is a four-year research programme funded by the Ministry of Business, Innovation and Employment (MBIE), and supported by the Ministry of Primary Industries (MPI), that is evaluating post-earthquake recovery trajectories in the coastal environment. Its geographic scope includes earthquake-affected coastal areas between Oaro in the south, and Marfells Beach in the north.

The information is presented in an easily digestible format consisting of a series of comparable maps, along with tables, graphs and site photographs to provide detail and highlight specific points.

With respect to this report, surveys completed or currently underway within the RECOVER project on the Marlborough coastline include:

- Mapping of indigenous dune system remnants throughout the study area.
- Recruitment of the indigenous sand-binders spinifex (*Spinifex sericeus*) and pīngao (*Ficinia spiralis*) on the post-quake uplifted beaches.
- Distribution of red katipō (*Latrodectus katipo*) within earthquake-affected dune systems.
- Distribution of banded dotterel / pohowera (*Charadrius bicinctus bicinctus*) nesting pairs to determine important areas along the coast, and
- Vehicle tracking measurements throughout the study area.

We also provide some preliminary results from three longer-term beach monitoring sites (located at Mussel Point, Aerial Beach and Long Pont), that illustrate current conditions and earthquake-related change on sandy beaches typical of the wider coast.

Temporal aspects and limitations

It is important to note that most of our surveys were designed to support a three-year longitudinal study aiming to characterise aspects of the 'recovery trajectory' for important values on the coast. A core research strategy within the RECOVER project is to establish whether the recovery is 'on track' based on a limited period of data collection. In this case, the research programme covers the period 2-5 years after the earthquake, even though some aspects of the environment will take much longer to reach a 'fully recovered' state, and partially depend on dynamic elements that are expected to undergo ongoing change. Despite its time-limited aspects, this research strategy can help to identify barriers to recovery and other potentially undesirable changes that could benefit from management interventions so that the best outcomes of recovery can be progressed or achieved.

These aspects should be kept in mind when interpreting the results presented here. For some topics (e.g., beach responses to uplift) we have been able to include information on two points in time which provides an indication of recovery processes and/or current trends. However, further research will be important to follow continuing changes. We also provide some comments on information gaps and potential topics for further research that are not currently addressed within the RECOVER project's scope.

2 Background

2.1 Changes to Marlborough beaches

Impacts of earthquake uplift are the primary focus of this report, although there are also erosion and deposition processes that are acting on the post-quake landscape and producing important additional changes. In uplifted areas, shorelines have moved seaward, essentially creating new land above the reach of the tide. In Marlborough, the changes have been manifested as a physical widening of many beaches that offers more opportunity for off-road vehicle access to the coast (Fig. 1.1). This has become particularly noticeable at headlands and other natural barriers that were previously impassable at high tide. Additionally, these beach responses are driving ecological changes in the location of key ecosystems such as sand dunes and storm beaches. Similarly, wildlife habitat and movements have been affected, although specific impacts are poorly understood. Together, these changes confer unique challenges for coastal conservation and management in earthquake-affected areas. To address these, there is an urgent need to assess and respond to the new spatial configuration of important values and potential threats to their recovery and long-term persistence.

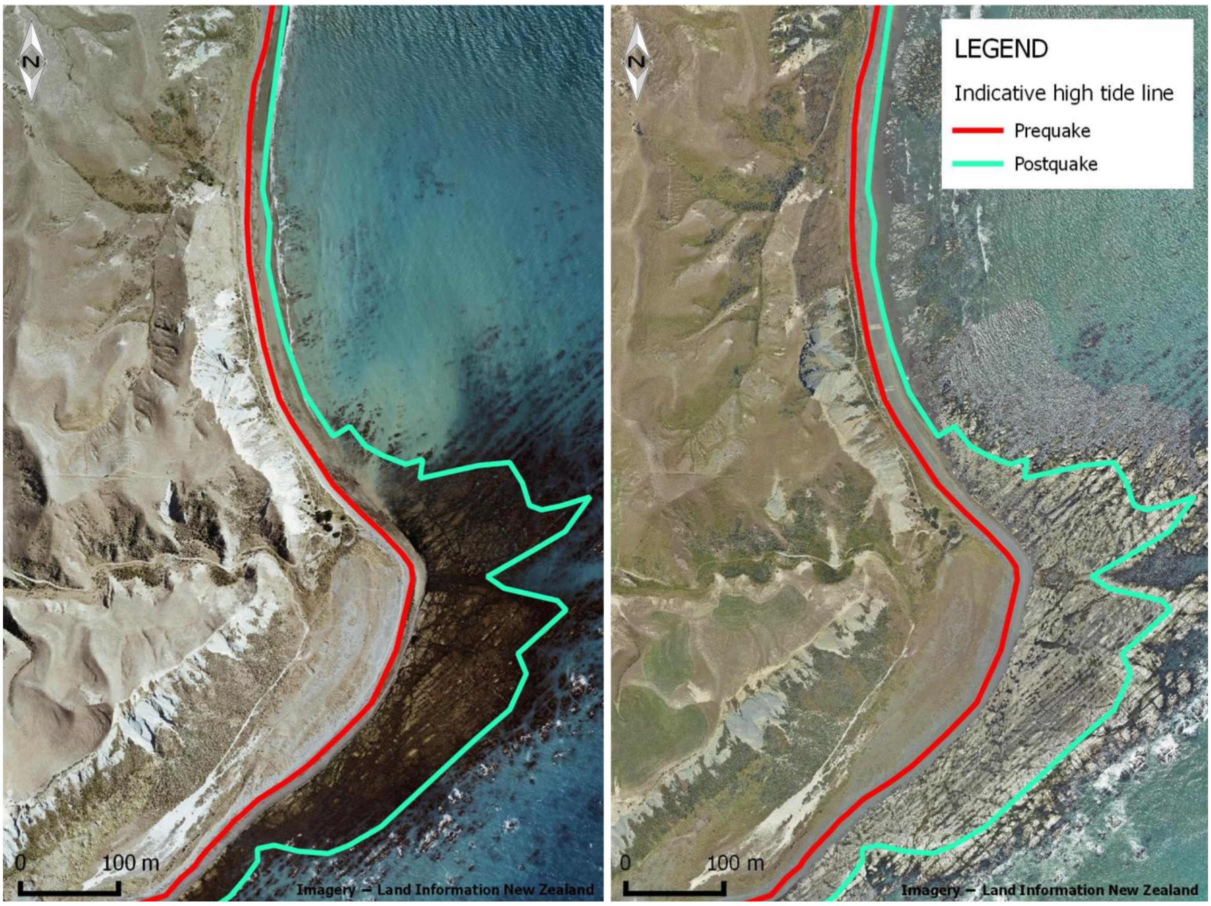

Fig. 1.1 Example of shoreline position changes associated with tectonic uplift at Long Point on the Marlborough coast showing pre-quake imagery (left), and post-quake imagery (right).

2.2 Reconciling recreational access and vehicle impacts

Off-road vehicles (ORV) present many possibilities for accessing remote areas where there are no formed roads (Fig. 2.1). In many parts of the world, ORV access is reportedly increasing, which may be attributable to a greater awareness of the access opportunities through communication channels such as websites and social media. In many cases, their cumulative effects have not been adequately managed. For example, Priskin (2003) reported that the number of ORV access points had increased by 115% between 1965 and 1998 on the Central Coast of Western Australia. In areas with a clearly defined 'road', drivers have also been observed to drive along the edge of the formed track, widening the damaged area (Davenport & Davenport 2006). Recent studies from Queensland showed that beach traffic is often more concentrated on the upper beach, but that the lower beach is used to varying degrees when exposed on lower tides (Schlacher & Thompson 2007).

Several studies have reported detrimental impacts of ORVs on the structure and function of sand dune ecosystems, along with other impacts on a variety of beach-dwelling species. For example, damage to the foredune prevents the formation of new dunes, and beaches with ORV traffic have dunes that are set further back from the high tide line than beaches closed to ORVs (Houser et al. 2013). Impacts of ORV traffic include sand compaction, erosion, and destabilisation of existing dunes (Davenport & Davenport 2006; Hosier & Eaton 1980; Houser et al. 2013). Because dunes act as a barrier against storm surge and sea-level rise, damage by ORVs can have major consequences for houses, roads, and other structures located behind dune systems.

The potential for damage to plant communities is an important component of ORV impacts on dunes because of the sand-trapping properties of dune plants. Groom et al. (2007) found much reduced densities of dune plants within areas open to OHVs in comparison to nearby areas where ORV traffic was prohibited under law. The impacts of ORVs included a reduction by up to 80% in the number of plant species, making rare species rarer and allowing dominant species to spread (Groom et al. 2007). In general, these vegetation-mediated impacts are additional to direct erosion effects of ORVs on dunes, and potentially more important in the longer term. In New Zealand, where the invasive *Ammophila arenaria* (marram grass) has displaced native sand-binders (Hilton 2006), ORVs may also cause a shift away from the native plant community and cause an overall decrease in the number of plant species present (Stephenson 1999), which are important aspects for the conservation of native dunes.

Shorebirds are among the most studied wildlife in relation to the impact of ORVs. Several factors contribute to their vulnerability. For example, ORVs can crush the nests of shorebirds, which can be a particularly problematic for species that lay camouflaged eggs in simple, cryptic nests such as 'scrapes' (Stephenson 1999; Weston et al. 2012). On Marlborough beaches, such species include banded dotterel (pohowera/tūturiwhatu) (*Charadrius bicinctus bicinctus)* and South Island pied oystercatcher (*Haematopus finschi*). Disturbance by vehicles may also cause birds to reduce their feeding time, increase time away from the nest (exposing eggs and chicks to predators), and decrease the number of nests (Defeo et al. 2009). Studies in Queensland found that only 34% of ORV drivers slowed down or changed course when encountering a shorebird, although partial beach closings with signs or rope did reduce the rate of egg crushing (Weston et al. 2012; Weston et al. 2014).

ORVs are also known to affect the beach invertebrate community. Crustaceans, polychaete worms, and clams all live in areas of the beach that are regularly used by vehicles (Davies et al. 2016; Schlacher et al. 2007; Schlacher et al. 2008). Even on low-trafficked beaches (e.g., with fewer than 50 vehicle passes per day), a 30 % reduction in invertebrate counts has been reported in comparison to untrafficked beaches nearby (Davies et al. 2016). In New Zealand, several studies have reported negative associations between ORV use and the health of sandy beach shellfish communities. Brunton (1978) showed that toheroa (*Paphies ventricosa*) actively move to the surface of the sand after being driven over by vehicles. It is suspected that toheroa confuse ORVs with crashing waves and rise to the surface to feed, which may expose them to predation by gulls (Brunton 1978). Other studies found that a significant percentage of juvenile toheroa are crushed in areas with vehicle use, which is in-part due to the distribution of juveniles being concentrated in the upper intertidal zone (Hooker & Readfearn 1998; Moller et al. 2014; Williams et al. 2013) (Hooker and Readfern 1998). Similarly, other species including the thin wedge shell (*Macomona liliana*), cockle (*Austrovenus stutchburyi*) and tuatua (*Paphies donacina* and *P. subtriangulata*) are found at depths <10 cm, and therefore susceptible to crushing by vehicles in the intertidal zone (Stephenson 1999; Taylor et al. 2012).

In general, the severity of ORV impacts depends on factors such as the frequency and type of traffic, composition and vulnerability of the biological communities present, temporal effects such as co-occurrence with nesting periods, and the precise location of vehicle tracking in relation to sensitive areas. Methods to control these impacts include area-based measures, which have been implemented in several parts of New Zealand to date. For example, the Tauranga City Council banned vehicle use on beaches (with some exceptions) in 2007 using a bylaw that was subsequently updated in 2018 to provide for a permitting system to authorise special cases (Tauranga City Council 2018). The Whangarei, Waimakariri, and Kapiti District councils have also banned vehicles from certain beaches or segments of beaches (Kapiti Coast District Council 2009; Waimakariri District Council 2016; Whangarei District Council 2009).

In relating the themes of the above review to the current situation in post-earthquake Marlborough, it is important to note the lack of objective data to quantify relevant aspects, and these include the type and volume of beach traffic, and its associated impacts. These information-poor aspects are common in New Zealand beach management contexts due to the relatively few studies that have addressed relationships between conservation and recreational use. In many respects, the following summary from Stephenson (1999) remains applicable today:

> *"The situation regarding vehicle impacts on the biota of the foreshore of sandy beaches in New Zealand remains uncertain. Although previous research provides a guide for management strategies with respect to vehicle use of sandy beaches and coastal dunes in New Zealand at a general level, some local research is considered desirable. Future research into vehicle impacts on the biota of sandy beaches and coastal dunes in New Zealand should include fundamental research to further underpin decision-making processes, and applied research to address problems and monitor the results of management at specific sites."*

Along several sections of the Marlborough coast, rocky reefs are also present seaward of sandy beaches and these are accessible to vehicles on lower tides. Although driving along a reef may alleviate impacts to the beach and dune ecosystems, it is likely to hinder recovery of the already severely affected algal community. For example, previous studies have shown that trampling causes a significant (up to 90%) reduction in cover of the dominant alga *Hormisira banksii* (Neptune's Necklace) on upper intertidal reef platforms. This species can take several years to return to its undisturbed state following a single disturbance event (Lilley & Schiel 2006; Schiel & Taylor 1999; Tait & Schiel 2011). These aspects illustrate the need to develop local solutions to address recreational access and ORV use.

Fig. 2.1 Off-road vehicle access has become more popular along the earthquake-affected coast as a result of new opportunities presented by beach uplift. Note tyre tracks from the dune vegetation above high tide to low tide reefs.

3 Methodology

3.1 Dune vegetation mapping

Dune ecosystem types were mapped across the entire study area in December 2018, with a follow-up survey the following summer. Each survey was conducted over four days and covered the full coastline from the Waima / Ure River in the south to Marfells Beach in the north.

These field surveys had two major objectives: quantifying the established ('old-dune') remnant systems and measuring the establishment of any new post-earthquake recruits of two priority indigenous sand-binding species, spinifex (*Spinifex sericeus*) and pīngao (*Ficinia spiralis*). Old-dune remnants were mapped as polygons using hand-held GPS units in the field. New recruits were measured as point locations. Additional measurements included the size of each colony, plant community composition, condition and threats.

3.2 Beach monitoring transects

Long-term monitoring sites were established at several beaches along the Marlborough coast in 2018 (Fig. 3.1, 3.2). On sandy beaches, the monitoring focussed on beach and dune responses to uplift effects, and surveys to support beach restoration initiatives as part of the Beach Aid collaborative project between the UC, MDC, Department of Conservation (DOC), and East Coast Protection Group (ECPG). Additional study sites were established on pea- gravel beaches such as Airstrip Beach (Fig. 3.2b) to support other work on the spatial distribution of nesting sites for banded dotterel / pohowera (*Charadrius bicinctus bicinctus)*. This beach also supports a small colony of sea holly (*Eryngium vesiculosum*) that is currently listed as a 'nationally vulnerable' species in the New Zealand Threat Classification System (de Lange et al. 2018).

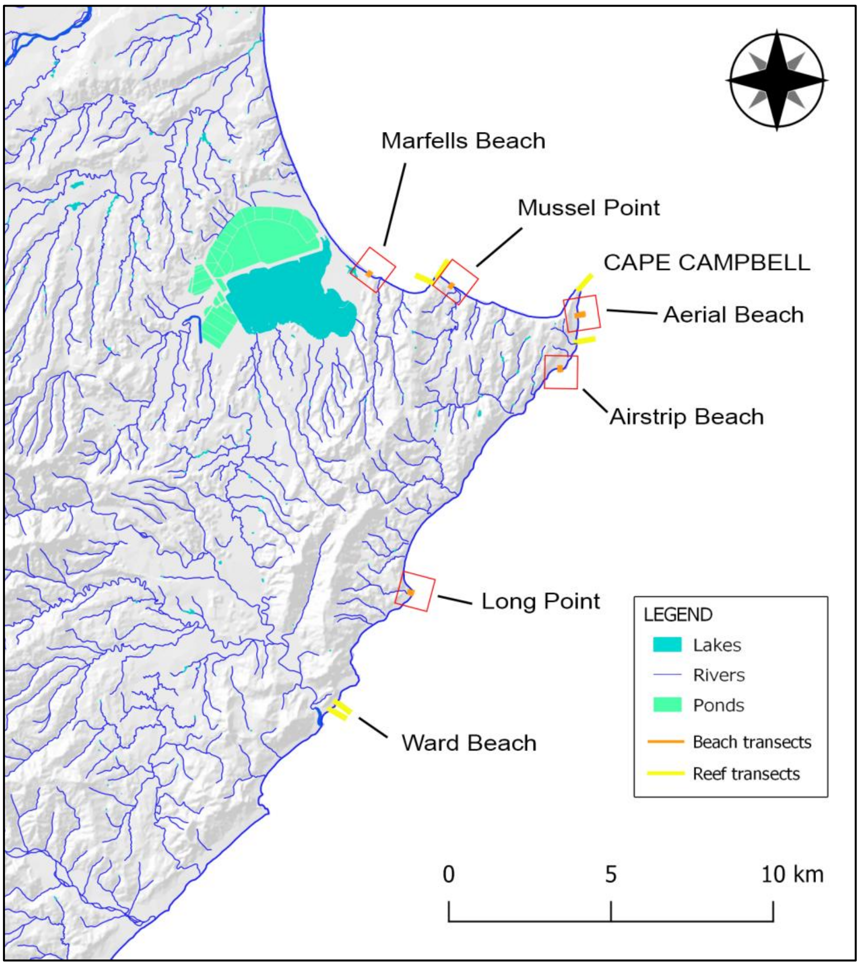

Fig. 3.1 Location of UC beach and reef monitoring sites on the Marlborough coast.

Surveys at sandy beach sites are designed to monitor change in pre-earthquake spinifex dune systems to assess their responses to earthquake impacts, with the exception of the Aerial Beach site. For the latter, the long term transects are primarily designed to monitor the main trial site for the Beach Aid project, as there are no remnant spinifex dunes at this site.

At each monitoring site, two shore-perpendicular sampling transects were established. An origin point for the first transect (Transect 1) was established at a random point in the backdune swale within the remnant spinifex dune system (where present). At most sites this location was in the transition zone between the dune system and more stable terrestrial vegetation types (typically grassland). The second transect was cast 50 m to the south at Aerial Beach. At Mussel Point and Long Point the distance between transects was 30 m and 20 m, respectively, with the closer spacing being necessary due to the small size of the spinifex remnant dunes that were the focus of the monitoring.

3.3 Katipō surveys

A pilot survey was completed in the 2019 summer to support an evaluation of the implications of uplift for red katipō (*Latrodectus katipo*) with regard to the potential for longer term impacts associated with dune system changes, and more immediate restoration opportunities associated with local initiatives such as Beach Aid. Katipō spiders are a flagship wildlife species for beach management in New Zealand and the earthquake-affected area is a previously reported population hotspot (Anderson & Anderson 2019; Patrick 2002). Katipō are the only native venomous spiders in New Zealand and have a restricted coastal distribution mainly associated with sandy beach ecosystems (Forster & Forster 1973; Griffiths 2001). There is also considerable evidence of decline since the 1970s (Hann 1990), which contributes to their current conservation status of 'at risk – declining' in the New Zealand Threat Classification system (Sirvid et al. 2012).

The particular focus of the pilot survey was the development of a methodology for spatially-explicit assessments of katipō abundance to enable the comparison of different areas within sand dune ecosystems. In our case, the areas of interest include the potential dune migration zone created by the uplift of sandy beaches. The specific objective of the pilot survey was to assess the spatial variation ('patchiness') of katipō populations at four sandy beach sites to inform the design of a larger scale survey to be completed in the 2020 summer in collaboration with local researcher Mark Anderson. The four sites chosen were Long Point, Aerial Beach, Mussel Point, and Marfells Beach, all of which will be included in the larger scale assessment.

At each site, a survey area of 30 m x 50 m was established with the long axis parallel to the foredune crest, which was further subdivided into three 10 m x 50 m areas representing different zones within the dune system. The 'foredune face' zone was defined as a 10 m wide belt seaward of the foredune crest, which at most sites included all or the majority of the front dune face. The 'foredune back-slope' zone was defined as a 10 m wide belt landward of the same position (foredune crest), and the 'backdune swale' zone was another 10 m wide band immediately adjacent to landward. The latter typically included a swale landform and/or continuation of the foredune back-slope. At all sites, the foredune crest was readily identifiable and relatively linear within the survey area.

All of the above areas were thoroughly searched for katipō webs which have a characteristic architecture (Griffiths 2001), and the results of May-June surveys are presented here. The position of all webs was recorded with a hand-held GPS and field notes, and the coordinates were subsequently checked and refined with the assistance of 0.2 m post-quake imagery. Katipō occupancy was established for all webs found and individuals were recorded as either juvenile or mature, with sex also recorded for the latter, as recommended in recent studies (Costall & Death 2009, 2010).

3.4 Banded dotterel surveys

Banded dotterel census surveys were completed for the Waima / Ure River to Marfells Beach coastline in November 2018 and 2019. A mobile GPS application (Gaia GPS) was employed in the field to record the location of individual birds and breeding pairs along with associated attributes including bird behaviour, presence of juveniles, and position on the beach. Nesting pairs were identified on the basis of territorial behaviour. Territorial overlaps were discriminated by having two observers following the movements of adjacent breeding pairs to assess their characteristic ward-like behaviour, which includes the 'escorting' of intruders to beyond the territorial range, in addition to distraction displays such as rat-runs when intruders are in closer proximity to the nest or chicks. Waypoints were positioned at the estimated midpoint of the territory based on these observations and at the location of first sighting for individual birds. Additional searches were made for nests at two locations (Ward Beach and Canterbury Gully) to verify the correlation between the above behavioural signs and the presence of nesting pairs. Four pairs of birds were tracked at each location and in all cases either a nest or young chicks were present within the territory as identified using the above technique.

3.5 Off-road vehicle tracking

Vehicle tracking measurements were made at periodic intervals throughout the study area during the dotterel census survey completed in 2018 and 2019. At each monitoring point the cumulative width of visible vehicle tracks (as measured in the shore-perpendicular direction) was recorded to the nearest metre. This measure reflects the distance between the tyre tracks of individual vehicles, summed across the shore profile, or in the case of heavily tracked areas, the cumulative width of the beach that was tracked. To avoid biases introduced by the presence of recent tracks on the lower beach (below the position of high tide) which were only visible at some sites and dependent on the state of the tide, only tracking above the high tide line is reported here. Additional notes were taken on transition points between areas of noticeably different tracking patterns, for example, where tracks were seen to fan out or converge in response to barriers and topographic changes, and at the location of turnaround areas and access points.

Fig. 3.2 Beach response monitoring. (a) Beach monitoring transect at Mussel Point. (b) RTK-GPS survey underway at Airstrip Beach to support UAV (drone) mapping of the uplifted beach.

4 Results and discussion

4.1 Dune mapping and recruitment

Comprehensive mapping of old-dune remnants in the study area shows that the distribution of indigenous dune vegetation is highly patchy for both of the priority sand-binding species (spinifex and pīngao) in this section of the Marlborough coast (Fig 4.1).

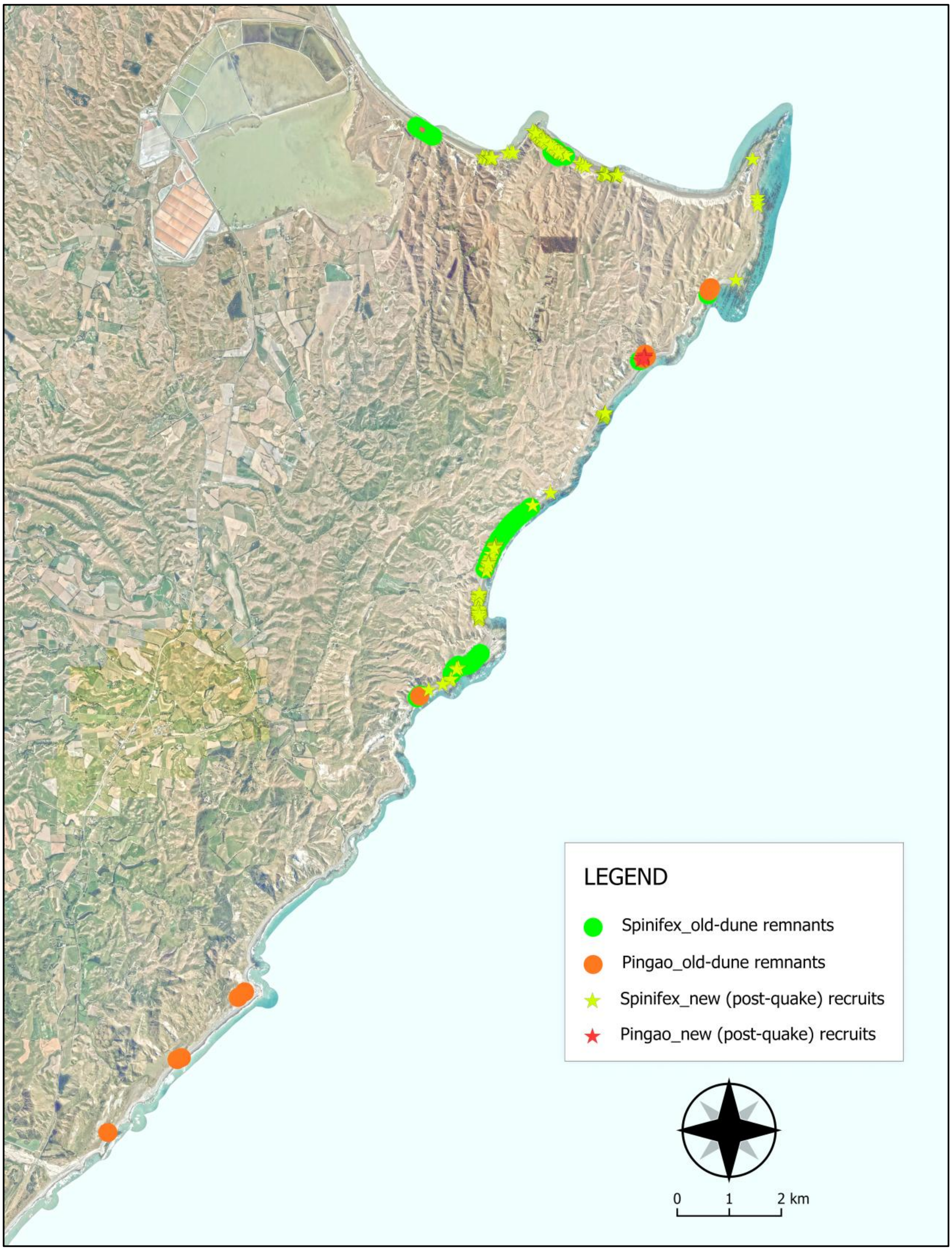

Fig. 4.1 Whole-coast overview showing the location of pīngao and spinifex old-dune remnants and new (post-earthquake) recruits, as recorded in summer 2019. Note that the northern end of the survey area was at Marfells beach and extensive stands of spinifex are known to be present further north in Clifford Bay.

Pīngao

The small number of pīngao was particularly notable, with only old-dune remnants found in four areas, and new recruits recorded only at Canterbury Gully. There are also clear signs of recent decline in some of the existing colonies, such as at Canterbury Gully where old root mats provide evidence of much greater vegetation cover that has since perished (Fig. 4.2b). Similar effects are apparent at Airstrip Beach (Fig. 4.4c), where historical photos illustrate a massive decline in pīngao cover in recent years. Taken together, the results suggest a trend of ongoing decline associated with recent pīngao mortality and a lack of recruitment across the coast as a whole.

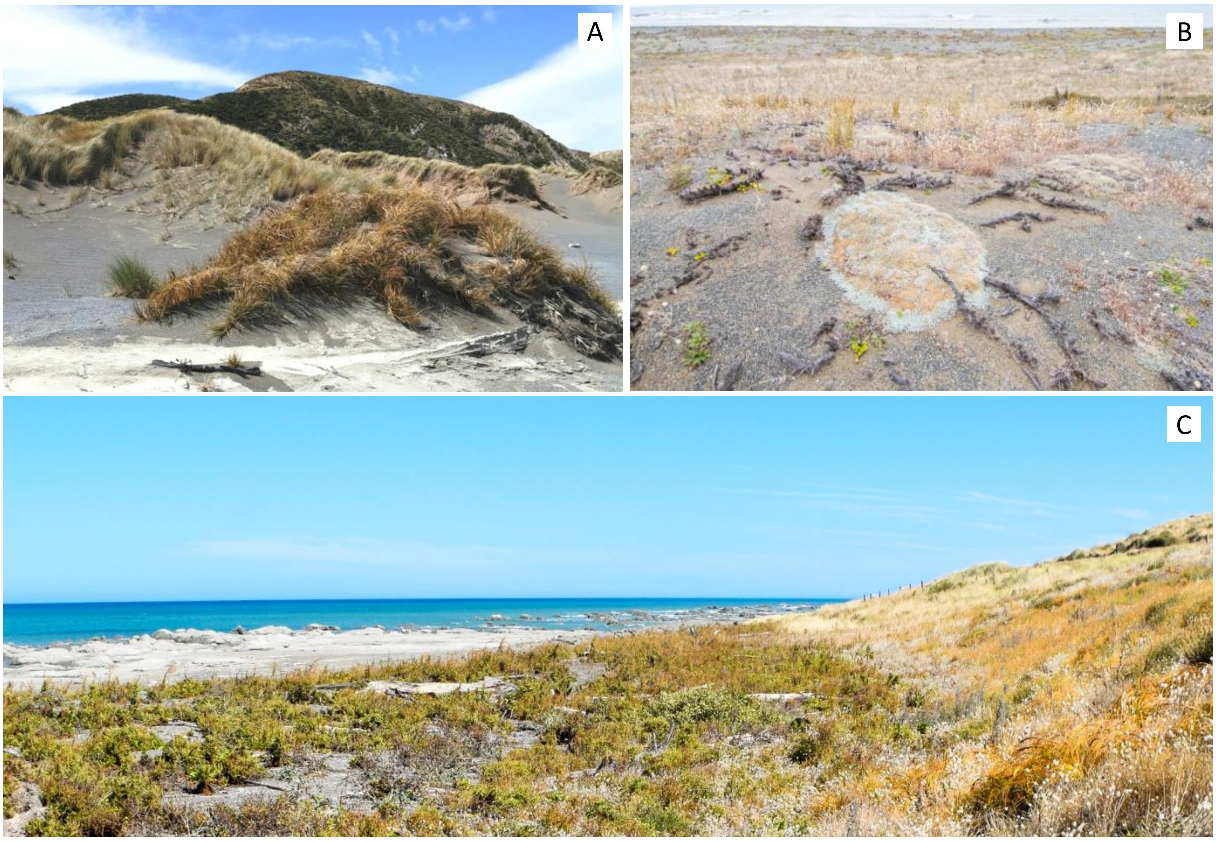

Fig. 4.2 Old-dune pīngao (*Ficinia spiralis*) remnants on the Marlborough coast. (a) example of a small isolated pīngao dune that has resisted marram invasion south of Long Point. (b) pīngao root mats are signs of recent decline at Canterbury Gully. (c) at Airstrip Beach the pīngao colony is now confined to the front face of an old terrace (on right) and has declined drastically in recent years.

Spinifex

Although remnant spinifex dunes are found throughout the study area, relatively large remnants are restricted to three main areas south of Marfells Beach (Fig. 4.1). In all three areas (Long Point, Booboo Stream, and Mussel Point), old-growth spinifex is found on sandy beach terraces and hill slopes that are now located a considerable distance inland. This illustrates the potential resilience of these ecosystems in the face of uplift events, which have been relatively frequent in this area in geological time (Ota et al. 1996). It is likely that these colonies represent relatively old dune systems that have successfully resisted marram invasion over the years.

Recruitment from the older remnants is reflected in the presence of smaller patches at a variety of locations across the study area (Fig. 4.3). These are generally located in the vicinity of marram-dominated dunes but have established in favourable areas. In nearly all cases, these spinifex patches are located at the seaward limit of the pre-quake vegetation, indicative of a competitive advantage over marram in this position. The distribution of these smaller patches has an apparent association with proximity to old-dune remnants. For example, only two such patches are located within the large area of coastline between Mussel Point and Canterbury Gully that is also a prominent gap in the old-dune distribution.

Across the coast as a whole, a total of 262 recruits of height > 20 cm were recorded in 2019, all of which were located seaward of the pre-earthquake dune toe on the uplifted beaches. The pattern of recruitment exhibits strong spatial patterning that highlights the role of old-dune areas as seed sources (Fig. 4.3, 4.4). This aspect has likely played an important role in the persistence of spinifex in the area over recent decades, and is consistent with the pattern of smaller colonies that appear to have become established more recently, although in general remain very scarce. There is potential for spinifex dune expansion in areas of uplift if spinifex recruitment is successful relative to that of potential competitors such as marram grass.

Fig. 4.3 Examples of pre-earthquake spinifex (*Spinifex sericeus*) dune ecosystems on the Marlborough coast. (a) the old-growth spinifex dune system at Mussel Point extends a considerable distance inland on the face of an old beach terrace that has remained dry and sandy. (b) a typical small colony located north of Long Point at the position of the pre-earthquake dune toe. These small colonies are mostly clustered around old-growth seed sources. (c) the extensive old-dune system in the Booboo Stream area has retained a high degree of natural character. Several large sections of the dune system are dominated by spinifex with a considerable area in relatively unmodified condition. Factors contributing to the resilience of these old-growth systems are an important current focus.

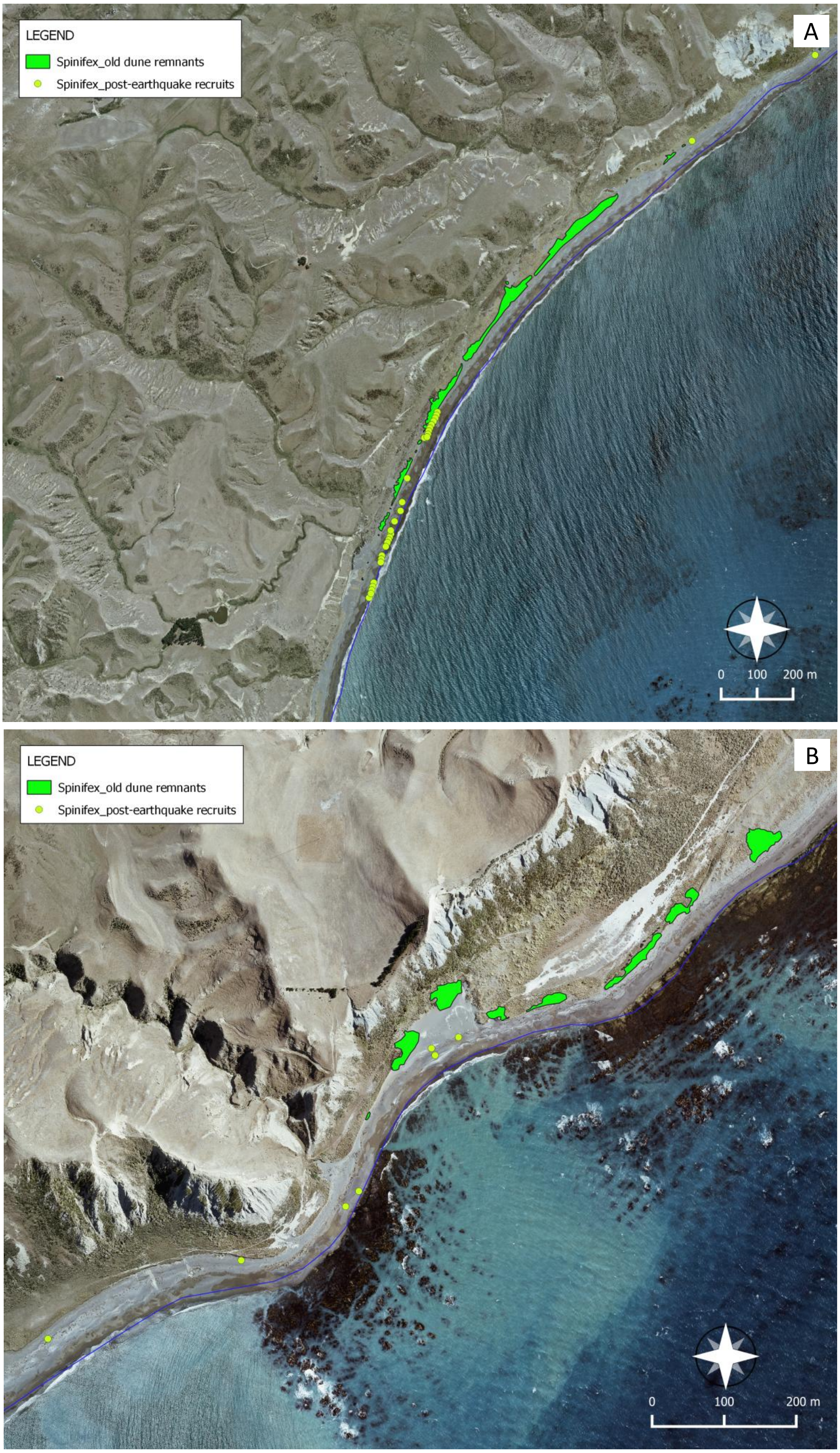

Fig. 4.4 Examples of spinifex (*Spinifex sericeus*) recruitment patterns on Marlborough's uplifted beaches. (a) striking recruitment pattern near the Booboo Stream old-dune remnant correlated with being downwind of prevailing wind direction and concentrated close to the new post-earthquake high tide mark on the uplifted beaches. (b) similar downwind effects from the old-dune remnants south of Long Point in 2019.

4.2 Beach monitoring transects

This section provides preliminary results from transect surveys at three sandy beach monitoring sites: Long Point, Aerial Beach and Mussel Point. Additional details are provided for a fourth site (Airstrip Beach), which is a gravel-dominated beach being investigated as a discrete case study.

4.2.1 Long Point

The Long Point study site is characterised by a several spinifex remnants that extend the full width of the dune system in some places, or otherwise occupy pockets between marram-dominated dunes (Fig. 4.5). Many of the spinifex remnants are interspersed with marram grass. This would be a good topic for additional monitoring to assess the potential for further invasion, which requires better knowledge of trends over time. However, some spinifex runners have extended into relatively open areas of sand (particularly to the south of the study site) indicating that ongoing dynamics are also important influences on spinifex presence and persistence. Large areas of intertidal reef were uplifted by up to 3 m in this section of the coast and this has created marked changes in the topography of the upper intertidal zone (Fig. 4.5).

Fig. 4.5 Location of beach monitoring sites at Long Point on the Marlborough coast.

Vegetation monitoring for the 2018-2019 period showed that the old dune system has been relatively stable (Fig. 4.6, 4.7). On this section of coast the old dune system now extends to edge of a steep gravel beach profile that occupies the area between the old dune toe (ca. 60 m on the transects) and a reef platform (ca. 100 m). Post-quake vegetation has established to ca. 90 m on the transect s (Fig. 4.6a). The new dune zone on the uplifted beach is only sparsely vegetated (< 20% cover), with the majority of the vegetation consisting of early coloniser species and a few spinifex runners extending into this area from the old dune toe, primarily in transect 1. These runners account for the higher percentage cover of the 'new dune landward' zone in transect 1 when compared to transect 2 (Fig. 4.6b), and are also reflected in the mean vegetation height data (Fig. 4.6c).

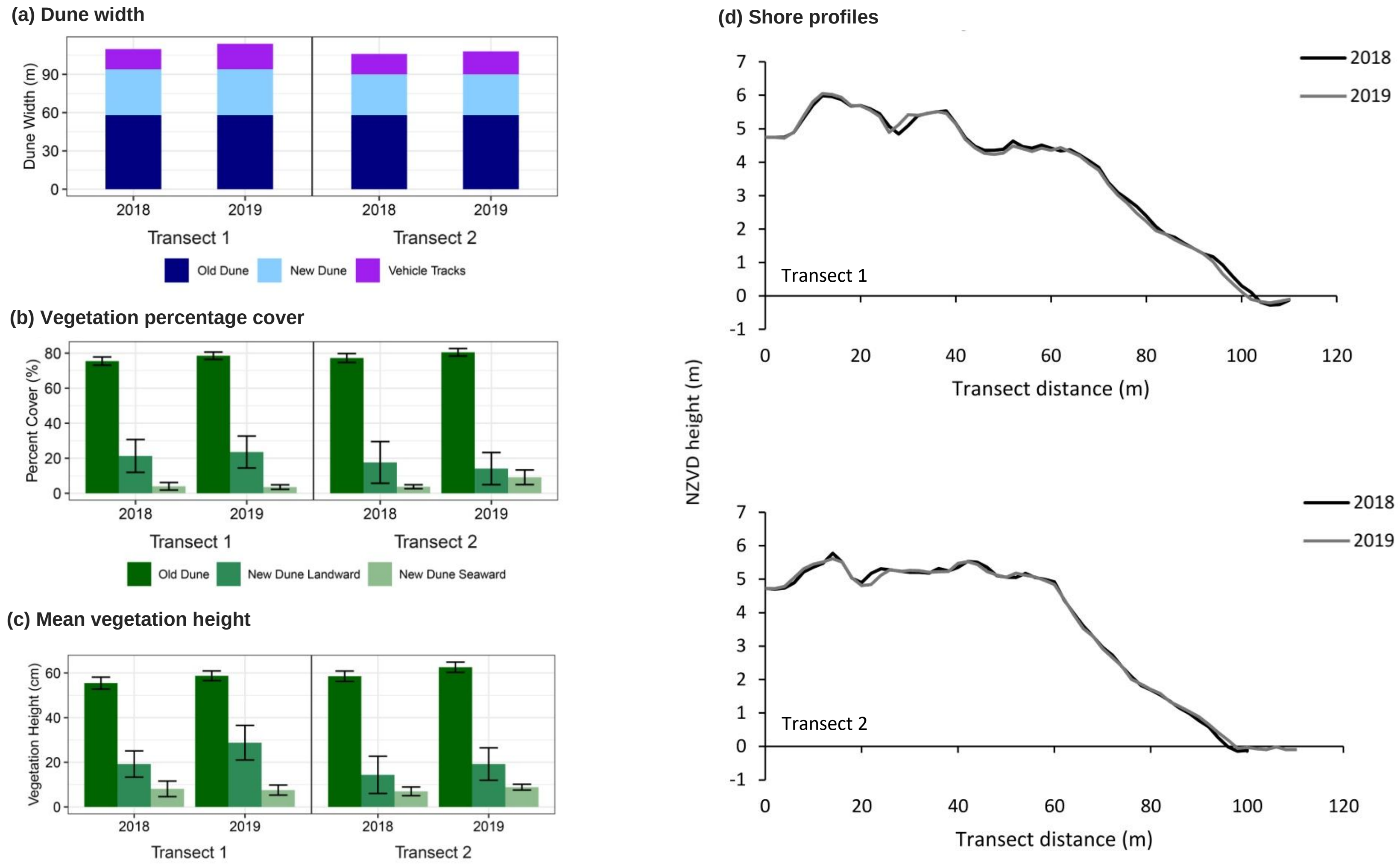

Fig. 4.6 Preliminary results from beach monitoring at Long Point over the summers of 2018 and 2019. (a) dune width, (b) percentage cover, (c) mean vegetation height, (d) shore profiles. The new dune zone is defined as the vegetation seaward of the estimated position of the old (pre-earthquake) dune toe, and is split in half (new dune landward and seaward) in graphs (b) and (c). Error bars are standard error of the mean for 2 x 2 m plots surveyed within each area.

This suggests the potential for spinifex dune movement to seaward and the available space being largely determined by decision on vehicle routes in relation to its natural seaward limit. Vehicle tracking on this stretch of beach is influenced by the relatively narrow area between the reef and dune toe, which provides high tide access on a sloping beach-face. On the new high tide beach the vehicle tracking footprint occupies at least two-thirds of the total area and has increased slightly between 2018 (16 m) and 2019 (18 m). However, a relatively well-formed track at the edge of the reef platform is the most used vehicle route and is available for most of the tidal range, depending on swell conditions

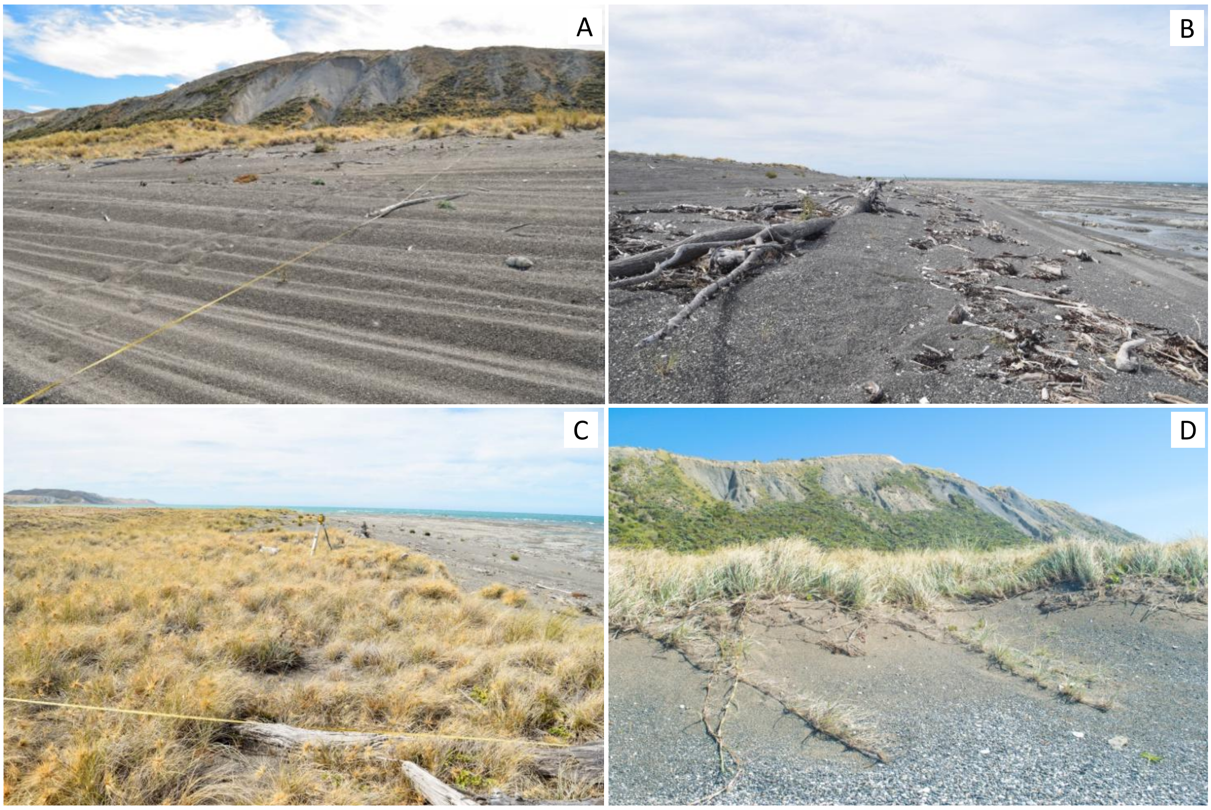

Fig. 4.7 Long Point beach. (a) vehicle tracking on the uplifted beach showing steep shore profile. (b) view looking north from transect 1. (c) looking north from the fore-dune crest on transect 2. In this area the relatively broad dune system remains dominated by spinifex (*Spinifex sericeus*) although it is interspersed with marram (*Ammophila arenaria*). (d) spinifex runners extending seaward from the position of the pre-earthquake dune toe on the uplifted beach.

4.2.2 Aerial Beach

Aerial Beach site is situated a few hundred metres south of the Cape Campbell lighthouse (Fig. 4.8). It is characterised by a steep, dense marram fore-dune with a sandy beach below. The back-dune area is fenced off from adjacent farmland and is also marram-dominated with no spinifex or pīngao present. However, a relatively large new spinifex colony (ca. 8 x 10 m) was already present on transect 1 in the summer of 2018, located near the position of the post-quake high tide mark. This is likely to have become established soon after the 2016 earthquake along with two other similar recruits to the south. Other new spinifex recruits have been observed on this beach since 2018, some of which have not survived. The latter is possibly related to drying out effects, as well as the potential impacts of browsing (e.g., rabbits), direct disturbance (e.g., vehicles) and inundation at high tide. Since monitoring began, however, there have been no major erosion events from storm tides or swell and this is reflected by the increase in vegetation cover on the uplifted beach above the level of typical high tides.

Vegetation monitoring in 2018-2019 showed that the pre-earthquake marram dune system has occupied the same footprint over this period (Fig. 4.9a), although with some erosion of the front dune face having occurred on transect 2 (Fig. 4.9d). However, the most striking result involves vegetation establishment in the 'new dune' area, which has increased substantially between 2018 and 2019. This is reflected by increases in vegetation cover (Fig. 4.9b) and mean height (Fig. 4.9c) within this area, as well as seaward expansion of the area of new vegetation on both transects (Fig. 4.9a). The latter is associated with the recruitment of new plants close to the post-earthquake high tide mark that have yet to be removed by a storm event (but could be in the future).

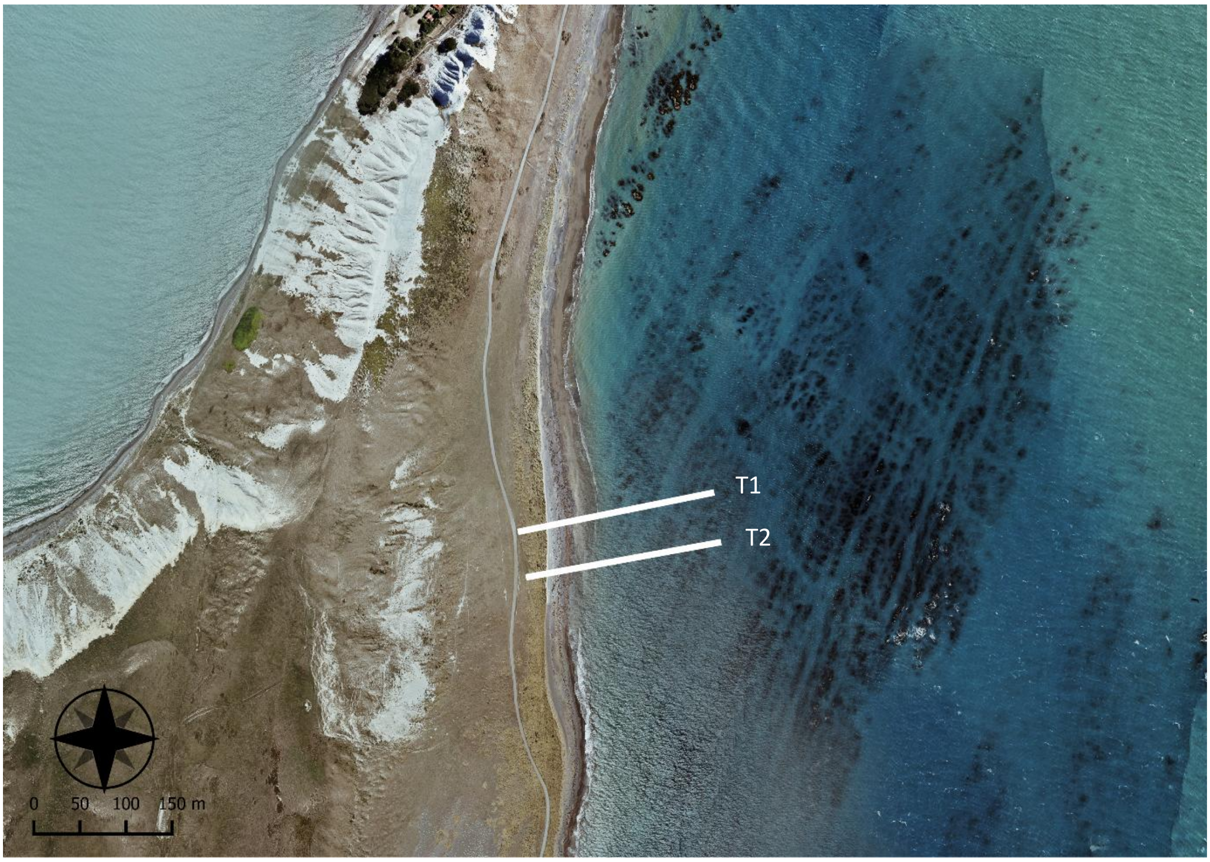

Fig. 4.8 Location of beach monitoring sites at Aerial Beach on the Marlborough coast. The cottages at Cape Campbell can be seen near the top of the picture.

The 'new dune' zone is now around 40 m wide on transect 2, and slightly less on transect 1 (Fig. 4.9a). Vegetation cover is rapidly increasing in this zone, especially in the seaward half where it has now reached 50% on transect 2 (Fig. 4.9b). The increased vegetation cover is now also having structural effects through the trapping of wind-blown sand. Accumulation of sand in the 'new dune' zone was indeed detectable in the shore profiles between 2018 and 2019 (Fig. 4.9d) and indicates the creation of a new dune habitat on the uplifted beach. Further progression of this process in presence of sand-binding species is expected to continue building a new dune system due to the abundance of sand supply. Human impacts on vegetation (both positive and negative) are therefore a key consideration at this time. At present, both marram and spinifex recruits have become established in the 'new dune' zone (Fig. 4.10).

Measurements of vehicle tracking showed markedly different results for the two transects between years. On transect 1, tracking increased from 4 m in 2018 to 15 m 2019, whereas on transect 2 tracking was similar between years (7m for 2018, 6m for 2019). These results, which are specific to the high tide beach, represent a relatively small tracking footprint when compared to other study sites (e.g., Long Point), even though vehicles are frequently observed on this section of the coast. This may indicate a tendency towards use of the well-defined tracks that are present on the upper beach, or alternatively greater use of the lower tide beach (or a combination of both). It is possible that the majority of ORV users in the Cape Campbell area have targeted lower tide conditions and may have come and gone within these periods since the access point at Marfells Beach is not far away. There is a greater chance that vehicles travelling further south (e.g., to Long Point) would encounter higher tide conditions even if this was not planned due to the greater distance and travel time involved.

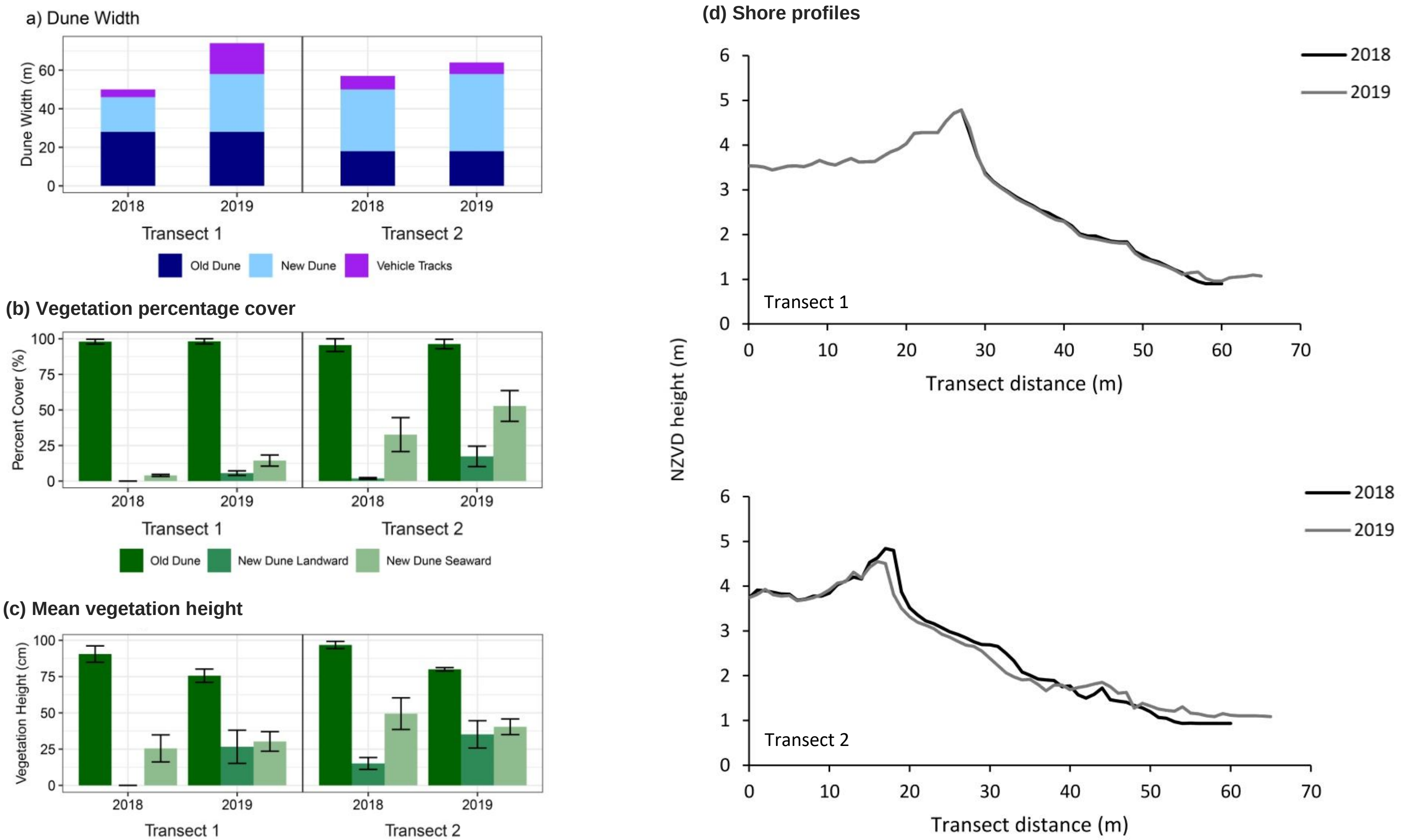

Fig. 4.9 Preliminary results from beach monitoring at Aerial Beach over the summers of 2018 and 2019. (a) dune width, (b) percentage cover, (c) mean vegetation height, (d) shore profiles. The new dune zone is defined as the vegetation seaward of the estimated position of the old (pre-earthquake) dune toe, and is split in half (new dune landward and seaward) in graphs (b) and (c). Error bars are standard error of the mean for 2 x 2 m plots surveyed within each area.

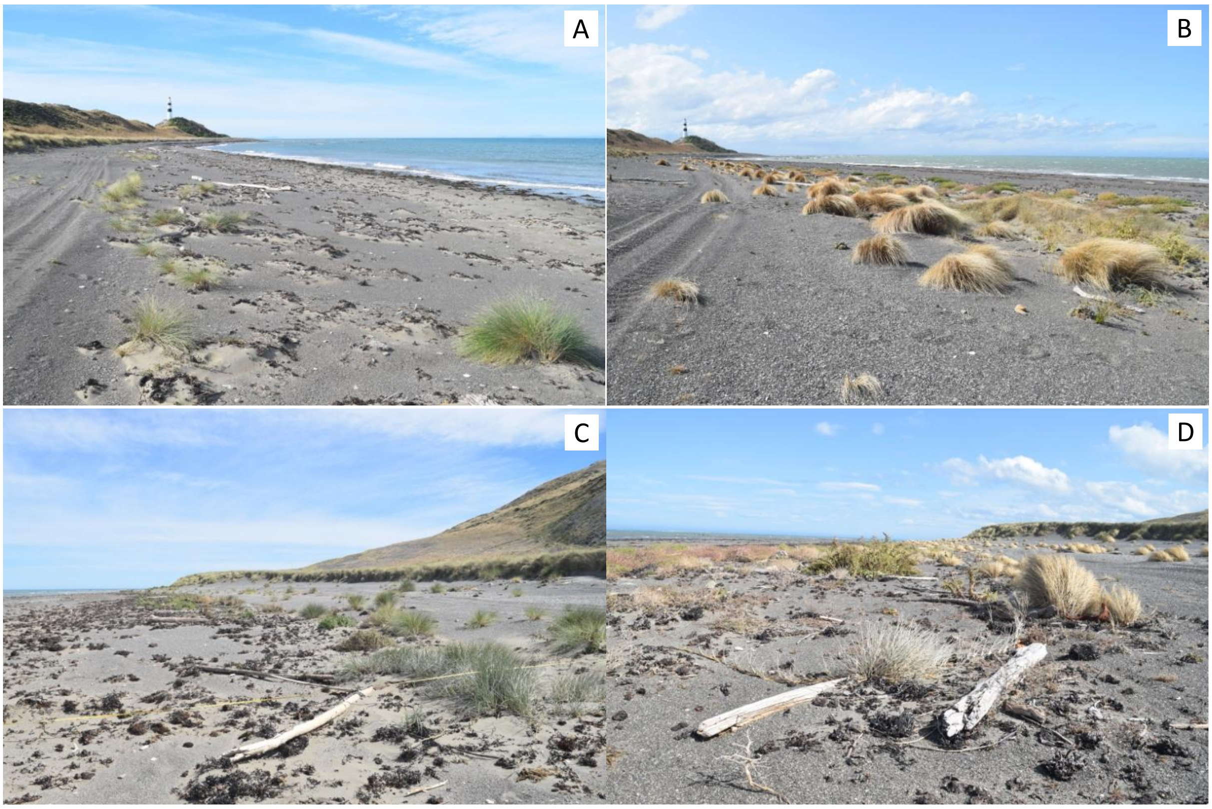

Fig. 4.10 Aerial Beach. (a) looking north towards Cape Campbell from transect 1 in 2018. (b) a similar view in early 2020 showing vegetation establishment in the new dune zone following marram control to support the Beach Aid project. (c) view looking south from transect 2 in 2018. (d) similar view looking south in early 2020.

4.2.3 Mussel Point

Mussel Point is located to the east of Marfells Beach campground. The lower beach has a more gentle profile than the beaches south of Cape Campbell due to the sheltering effect of the Cape (Fig. 4.11). The dune system is characterised by a marram-dominated fore-dune. There is also a well defined secondary dune at the study site which supports stands of knobby club rush (*Ficinia nodosa*). In addition, two small patches of spinifex are present on the fore-dune crest (one on each transect line) in the otherwise marram-dominated system, and there is a third patch further east near the mouth of Fishermans Creek. These are interpreted as being relatively new colonies since there is a relatively large old-growth spinifex dune system on the sandy hillside behind the beach (see Fig. 4.4) that is protected under a QEII National Trust covenant.

Vegetation monitoring for 2018-2019 showed that a 'new dune' zone of around 10 m in width has developed on the Mussel Point beach in response to earthquake uplift, which is less than at the other study sites (Fig. 4.12a). Within this area, vegetation cover has increased at transect 1, but not at transect 2 (Fig. 4.12b). This reflects the growth of several spinifex runners that have extended into the new dune zone from the pre-earthquake dune toe (Fig. 4.13a), and are also beginning to catch sand as seen in the shore profiles (Fig. 4.12d). This is also reflected by the vegetation cover increases being mainly seen in the landward half of the 'new dune' zone), in contrast to Aerial Beach where vegetation establishment in this zone has been greatest within the seaward half. The latter is associated with the arrival of new recruits that have established near the position of the new (post-earthquake) high tide mark. At Mussel Point there has been some plant establishment in the seaward half of the 'new dune' zone (Fig. 4.13b), but our monitoring to date shows that this band of vegetation has not increased appreciably since 2018 (Fig. 4.12b, c). Field observations have shown that there is considerable turnover in this area (some plants dying and other new plants establishing), which largely explains these effects.

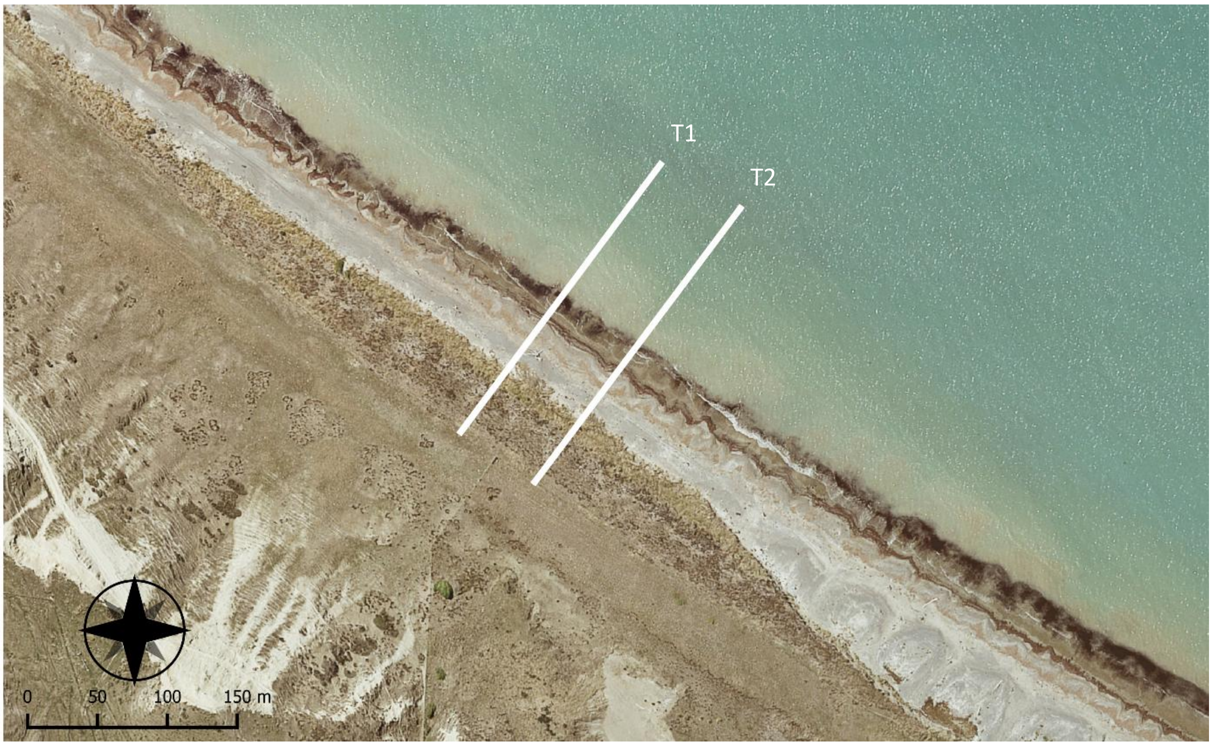

Fig. 4.11 Location of beach monitoring sites at Mussel Point on the Marlborough coast. The access track from the Peters' farm can be seen at bottom left.

Measurements of vehicle tracking reflect the presence of either one or two vehicle tracks within the new dune area on the uplifted beach, but there are typically many more tracks visible in the intertidal area further down. The measured tracks include some evidence of ORV users purposefully driving on the dune face, perhaps as a challenge for their driving skills. Obviously, this presents a threat to the development of spinifex dunes in the uplifted 'new dune' zone through impacts on the potential expansion of runners from the pre-earthquake dune system (Fig 4.13c), as well as the survival of new recruits (Fig. 4.13d).

As with the results for vehicle tracking at Aerial Beach (section 4.2.2) there are indications that the majority of ORV traffic is travelling in the intertidal zone on the beach at Mussel Point, which suggests that many recreationalists have targeted lower tide conditions (and indeed may have travelled onwards to the Cape). In combination with the small width of the high tide that was the focus of the monitoring reported here, these aspects explain why the signs of vehicle tracking are a lot less obtrusive at Mussel Point in comparison to the pea-gravel beaches south of Cape Campbell.

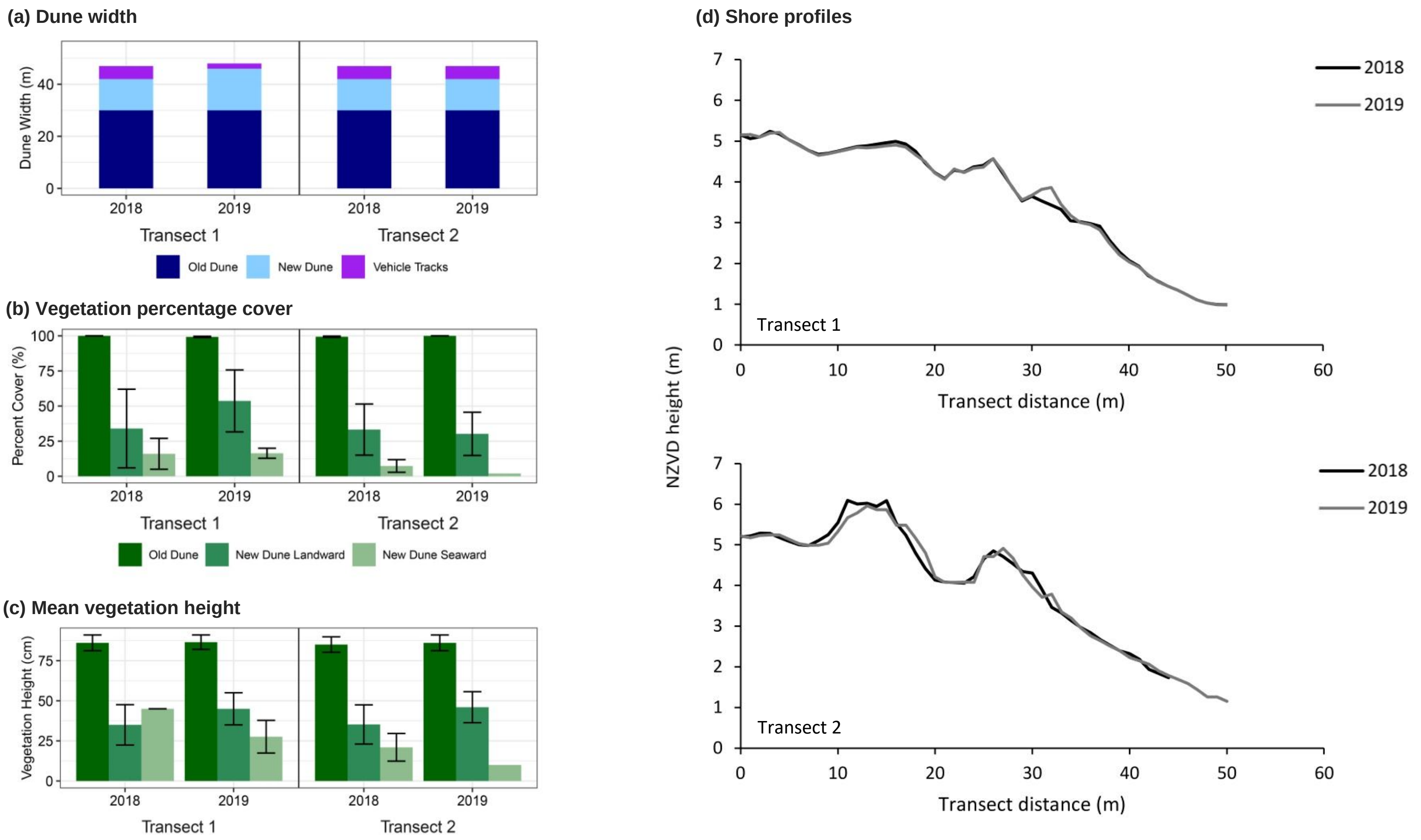

Fig. 4.12 Preliminary results from beach monitoring at Mussel Point over the summers of 2018 and 2019. (a) dune width, (b) percentage cover, (c) mean vegetation height, (d) shore profiles. The new dune zone is defined as the vegetation seaward of the estimated position of the old (pre-earthquake) dune toe, and is split in half (new dune landward and seaward) in graphs (b) and (c). Error bars are standard error of the mean for 2 x 2 m plots surveyed within each area.

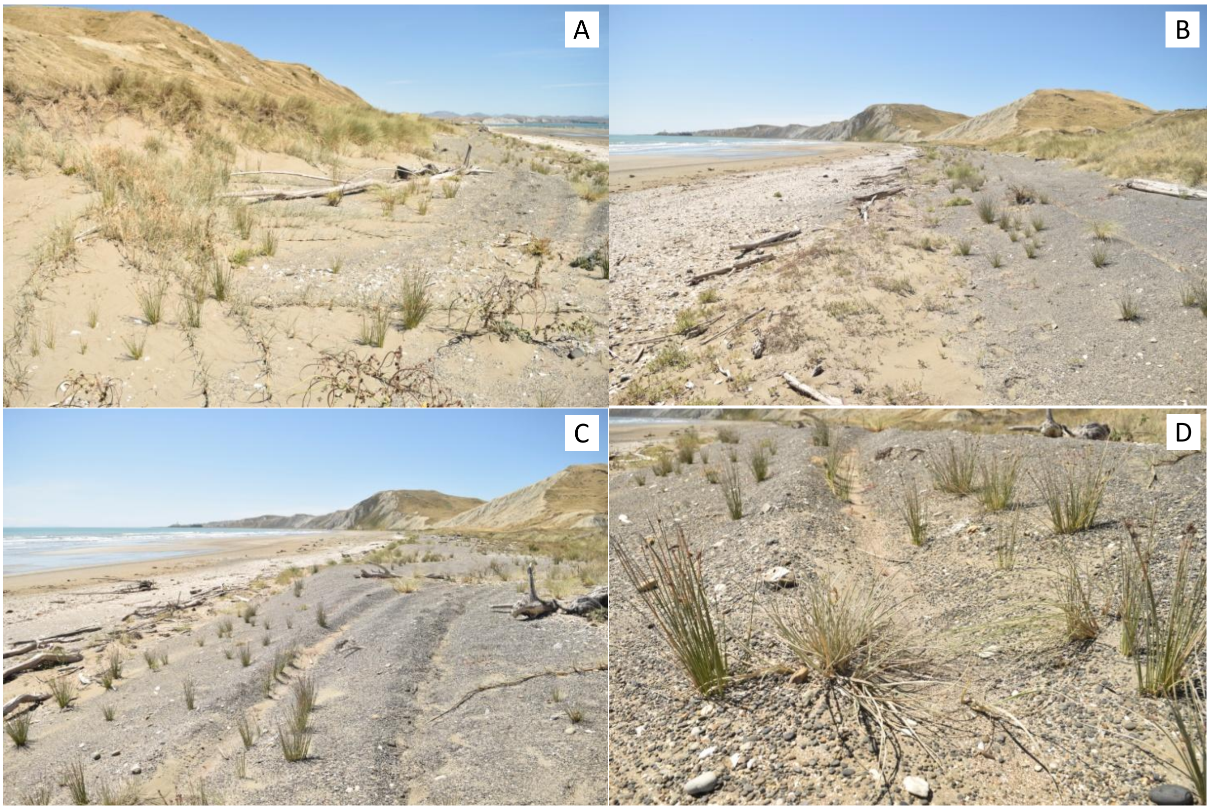

Fig. 4.13 Mussel Point beach. (a) spinifex runners extending into the 'new dune' zone on the uplifted beach. (b) view looking east from transect 2 showing the modest area of new beach (ca. 10 m wide) that has been uplifted above the post-quake high tide mark. (c) vehicle tracking on the dune face in the 'new dune' zone. (d) example of a new spinifex recruit in close proximity to vehicle tracks. Field observations have shown that the mortality of these post-quake recruits is relatively high at this site, with very few having become established and grown to appreciable size despite an abundance of seed sources nearby. The other species present in this photo is knobby club rush (*Ficinia nodosa*), which is also a characteristic coastal species often found in dunes.

4.2.4 Airstrip Beach

Airstrip Beach is located at a prominent kink in the coastline associated with a marked change in wave energies. The south-facing section of coastline is more exposed to swell action due to a gap in the offshore reef structure that is aligned with its southerly aspect. This has resulted in a gravel-dominated beach, with extensive wood deposits that provide important habitat for wildlife such as lizards. These include the Waiharakeke grass skink (*Oligosoma aff. polychroma*) that is currently classified as 'at-risk-declining' and is a characteristic local species (Marlborough District Council 2019b). This section of coastline has also been noted as a banded dotterel nesting area (Rob Peters, pers. comm.) and the outer corner of the beach is an important congregation and feeding site for a wide range of coastal bird species, including migrants (Mike Bell, pers. comm.).

Within the RECOVER project, this site is being monitored as a case study to support the wider investigation of banded dotterel spatial ecology and to characterise potential vegetation changes on uplifted gravel-dominated beaches and other habitat-forming aspects, such as changes in wood deposition areas. Many important dynamics are expected to exhibit slower rates of change in comparison to the sandy beach sites. To address this, UAV (drone) surveys of uplifted beach habitats, including the nearby old-dune pīngao remnant, have also been done to facilitate longer term monitoring. To date, transect surveys completed in 2018 and 2019 have detected little change in the vegetation pattern, and the sea holly colony appears to have been relatively stable, at least over this recent period. The banded dotterel nesting case study is ongoing and has a focus on understanding the degree of spatial overlap between dotterel nesting grounds and recreational traffic at a relatively fine scale (see section 4.6). A location map and recent site photos are shown (Figs. 4.14 and 4.15).

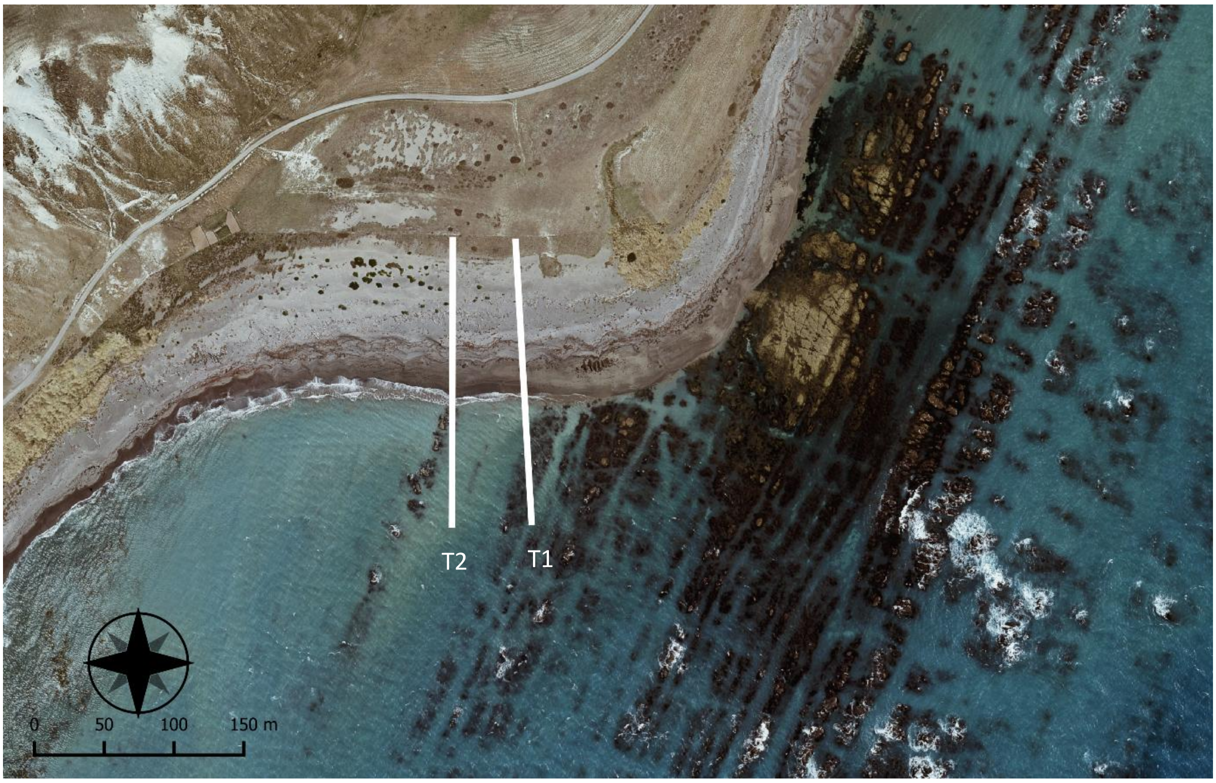

Fig. 4.14 Location of beach monitoring sites at Airstrip Beach on the Marlborough coast.

Fig. 4.15 Airstrip Beach. (a) view looking south from Airstrip Beach showing the extensive pea-gravel beaches characterised by wood depositions and salt-tolerant shrubs that are now uplifted from their pre-quake positions. (b) looking east along the beach towards a prominent corner in the coast that is an important bird congregation area. (c) view of the lower beach at transect 2 where new wood deposits are gradually accumulating. (d) a colony of sea holly (*Eryngium vesiculosum*) is located at the top of the uplifted beach in an area of relatively stable gravels.

4.3 Katipō surveys

Katipō densities were found to be highly variable both within and between study sites. The site with the greatest total abundance was Mussel Point (n = 28), followed by Marfells Beach (n = 24). In contrast, only two katipō were found at Aerial Beach and Long Point within the same size search areas (1500 m^2) in comparable locations with respect to the orientation of the fore-dune (Table 4.1). At Marfells Beach, 50% of the webs found were unoccupied in the back-slope and back-dune swale zones. On the fore-dune face, 12.5% of webs were unoccupied, and the average across all three zones was 32%. Although webs of other species were also found (particularly landward), the katipō webs have a relatively distinctive architecture. In many cases, the unoccupied webs showed signs of degradation (e.g., appearing collapsed or partially buried), that are consistent with the apparent absence of an occupant. At Mussel Point, similar results were obtained with 20% of the webs being unoccupied, all of which were found on the fore-dune face, and unoccupied webs were also found at Aerial Beach (Table 4.1). These results have implications for the design of survey methods to estimate katipō density based on counting webs alone, and may be related to seasonal effects.

Table 4.1 Summary of red katipō (*Latrodectus katipo*) densities within three morphologically defined zones† at each of four study sites on the Marlborough coast in the summer of 2019.

(a) Marfells Beach

Dune system zone	Total webs	Unoccupied webs	Adult females	Adult males	Juveniles	Total katipō
Foredune face	16	2	12	5	0	17
Foredune back-slope	6	3	1	1	0	2
Backdune swale	12	6	2	2	1	5
Total	34	11	15	8	1	24

(b) Mussel Point

Dune system zone	Total webs	Unoccupied webs	Adult females	Adult males	Juveniles	Total katipō
Foredune face	34	7	13	11	3	27
Foredune back-slope	1	0	1	0	0	1
Backdune swale	0	0	0	0	0	0
Total	35	7	14	11	3	28

(c) Aerial Beach‡

Dune system zone	Total webs	Unoccupied webs	Adult females	Adult males	Juveniles	Total katipō
Foredune face	3	1	2	0	0	2
Foredune back-slope	0	0	0	0	0	0
Backdune swale	0	0	0	0	0	0
Total	3	0	0	0	0	2

(d) Long Point

Dune system zone	Total webs	Unoccupied webs	Adult females	Adult males	Juveniles	Total katipō
Foredune face	2	0	1	1	0	2
Foredune back-slope	0	0	0	0	0	0
Backdune swale	0	0	0	0	0	0
Total	2	0	1	1	0	2

† dimensions of the study plot within each zone are 50 m x 10 m with the long axis running parallel to the fore-dune crest.

‡ see Table 4.2 which shows results from an additional site at Aerial Beach where the katipō density was much higher.

Across all sites 52 adult katipō were recorded, of which 32 were females and 20 males (Table 4.1). This pattern is consistent with the results of previous surveys that recorded a greater percentage of females. This has been attributed to the shorter life span of males (Forster & Kingsford 1983) , as well as their tendency to roam in search of females, which may reduce their detectability in searches focused on finding webs (Griffiths 2001). Very few juveniles were recorded in this survey, which was expected due to the late timing of the survey period. However, old egg sacs were observed in many of the webs occupied by females. Several webs were found in close proximity to others, and some of the close associations included shared web structures in which more than one spider was found, as has been reported in previous studies (Costall & Death 2009). Importantly, no false katipō (*Steatoda capensis*), were recorded in this survey. This may be a factor influencing the status of the Marlborough coast as a red katipō hotspot. The evidence for decline has coincided with the spread of *S. capensis* since its introduction from South Africa (Hann 1990), and with additional effects of habitat fragmentation associated with the spread of marram (Griffiths 2001). The displacement of katipō by *S. capensis* appears to be an ongoing process that is potentially assisted by disturbance processes due to differences in the dispersal behaviour of juveniles (Hann 1990).

Within the three dune system zones we sampled, the fore-dune face supported the highest densities at all four sites (Table 4.1). At this scale (10 x 50 m) the greatest number was recorded on the fore-dune face at Mussel Point (n = 27), being the equivalent of 540 katipō / ha. However, when all three dune zones are considered (30 x 50 m), the katipō density reduces to 187 katipō / ha. At Marfells Beach the overall density was also similar (160 katipō / ha). This result is lower than densities reported by Anderson & Anderson (2019) within three search areas of similar (1800 m^2) in the same area in 2019, for which the mean density was 319 katipō / ha. In both studies the search area was located in a similar position within the dune system and used the same (30 m) cross-shore dimension.This might represent the effect of spatial patchiness along the beach, which was also evident at other study sites.

A comparison of results from our three dune zones indicates that higher densities are associated with the fore-dune face at all four study sites (Table 4.1). Interestingly, these findings contrast with the nationwide pattern described by Patrick (2002) for both red and black katipō, which includes a preference for the landward side of the fore-dune (equivalent to the fore-dune back-slope study area in the present study), which offers more shelter from extremes of storms in comparison to the fore-dune face. Despite this, many of the webs found in our surveys were located in exposed positions on the fore-dune dune face. At Aerial Beach, where spinifex is absent in the pre-earthquake dune system, katipō were restricted to the fore-dune face, and the presence of dense marram stands landward of the fore-dune crest probably explains their absence in these areas. However, at Long Point, sparse spinifex interspersed with marram is found across the entire width of the pre-quake dune system (ca. 60 m), and yet katipō were found only on the fore-dune face. At Marfells Beach, the majority of katipō (83%) were found in spinifex (Fig. 4.16b), and the remainder (17%) were recorded in sparse marram grass which is consistent with previous studies (Smith et al. 2014). At this site, sparse spinifex interspersed with marram extends landward of the fore-dune and represents a continuation of relatively favourable habitat across all of three dune systems zones within our study area. Thus, the presence of katipō throughout the survey area (despite differences in densities) is consistent with previous evidence that links katipō distribution with relatively sparse vegetation, which supports their feeding strategy that relies on airflow between plants (Griffiths 2001; Patrick 2002).

Although the above results that suggest a strong influence from vegetation type, the overall abundance of katipō at Long Point and Marfells Beach presents a striking comparison since both sites have spinifex-dominated dune systems that are reportedly to be among the most favourable habitats (Costall & Death 2009; Griffiths 2001; Patrick 2002). This suggests the influence of large-scale factors additional to vegetation types and dune morphological zones. Factors that may be influencing the distribution of katipō along the coast are of particular interest, since this is directly relevant to the identification of important areas for protection. Findings from our pilot study indicate that these aspects deserve further research at a variety of scales to gain a better understanding of the overall picture.

Fig. 4.16 Red katipō (*Latrodectus katipo*) on the Marlborough coast. (a) an adult female katipō. Note prey items stuck to the web. (b) view along the fore-dune at Marfells Beach where katipō were found within sparse vegetation through the study area, though with highest densities being found on the fore-dune face.

One anomaly we addressed in the field concerned the unexpected result of low katipō numbers at Aerial Beach, since previous studies reported high densities in this area (Anderson & Anderson 2019). To investigate this, we established an additional survey area immediately adjacent to the original randomly-located survey area (to the north). The results were markedly different, with a total of 17 katipō recorded in the additional survey area, despite all other discernible habitat attributes (e.g., vegetation and dune morphology) being very similar between sites (Table 4.2). This provides an important indication of spatial variation and 'patchiness', even at this relatively small scale in terms of distance along the beach.

Table 4.2 Red katipō (*Latrodectus katipo*) density differences within in two adjacent survey sites (each 50 m in length) at Aerial Beach on the Marlborough coast in the summer of 2019. Site 1 is the original randomly-selected survey area. Site 2 is immediately adjacent to the north and was surveyed to investigate the apparent absence of katipō in the first survey in relation to previous studies that have reported high densities in this area (Anderson & Anderson 2019).

(a) Site 1 (original survey site)

Dune system zone		**Unoccupied webs**	**Adult females**	**Adult males**	**Juveniles**	**Total katipō**
Fore-dune face	3	1	2	0	0	2
Fore-dune back-slope	0	0	0	0	0	0
Back-dune swale	0	0	0	0	0	0
Total	3	0	0	0	0	2

(b) Site 2 (additional survey site)

Dune system zone	**Unoccupied webs**	**Adult females**	**Adult males**	**Juveniles**	**Total katipō**
Fore-dune face	3	12	5	0	17
Fore-dune back-slope	0	0	0	0	0
Back-dune swale	0	0	0	0	0
Total	0	0	0	0	17

Overall, findings from the pilot study point to the need to ensure comparability and account for variability when deriving metrics for the estimation of population sizes, such as density. In particular, there are difficulties in defining equivalent areas for comparisons between sites, as is needed for approaches that rely on sub-sampling (e.g., using quadrats or other plot-based methods). Similar considerations are important for the identification of important habitats and /or geographic zones within a given dune system, and these will be the subject of further research in our upcoming studies.

4.4 Banded dotterel nesting sites

The 2018 and 2019 surveys showed relatively consistent results for the overall number of banded dotterels recorded in the area between Marfells Beach and the Waima / Ure River. However, the total number of nesting pairs increased between years, and a greater number of chicks were observed in 2019 (Table 4.3).

Table 4.3 Summary of banded dotterel (*Charadrius bicinctus bicinctus)* observations made during whole-coast surveys in 2018 and 2019 between Marfells Beach and the Waima / Ure River on the Marlborough coast.

Banded dotterel observations	2018	2019
Breeding pairs	60	69
Chicks	2	17
Non-breeding individuals	29	21
Total birds	151	176

Banded dotterels were observed at a variety of locations in relation to the shore profile and intertidal range. Individual birds were often seen feeding near the shoreline. Pairs tended to move around together, and were often found well above the high tide line, especially on the uplifted beaches where this supratidal zone is relatively wide. Nest searches at Ward Beach and Canterbury Gully were successful in locating eggs or chicks within the estimated territories of adjacent pairs (Fig 4.17). Although only two single chicks were observed in the 2018 survey, three family groups with two chicks, and two with three chicks were observed in 2019. Although these observations are encouraging as an indication of chick survival rate, they may also reflect improved attention to spotting chicks that developed over time, given that they can be very hard to detect when small (Fig. 4.17b). These aspects require further research to evaluate the contribution of threats associated with risks to nesting success. Potential influences to consider include changes in the overall population size and effects on clutch survival rates (Norbury & Heyward 2008).

Fig. 4.17 Banded dotterels (*Charadrius bicinctus bicinctus)* on the Marlborough coast. (a) adult bird in a typical nesting territory on a pea-gravel beach. (b) small chick belonging to the parent bird in (a), at Ward Beach. (c) nest site (circled) at Canterbury Gully. The three eggs are laid in a shallow 'scrape' that is difficult to see. Note tracking nearby.

Within the RECOVER programme our main focus has been to elucidate spatial aspects of banded dotterel nesting sites in relation to coastal uplift and recreational use. The above-mentioned census surveys provide important information on the spatial distribution of nesting sites, as indicated by breeding pairs, along the coast. However, additional work is required to determine whether some parts of the shore profile are more important than others for nesting sites.

Results to date show a relatively consistent longitudinal (along-the-coast) distribution pattern between years that can be broadly described as clusters of breeding pairs that tend to favour pea-gravel beaches in certain parts on the coast. Exceptions to the latter include the south-eastern corner of Marfells Beach, Aerial Beach (south of Cape Campbell), and the beaches north of Long Point, all of which have a more sandy / mixed sand-gravel character and are home to a few breeding pairs. The overall pattern can be visualised as heat map that clearly identifies areas where higher densities of nesting pairs are found (Fig. 4.18). The highest densities were found at Long Point in both years. Other important locations include the Chancet Rocks to Ward Beach area, Needles Point, Waima / Ure rivermouth, and beaches between Cape Campbell and Canterbury Gully.

In upcoming research we hope to gain a better understanding of cross-shore nesting habitat preferences since this information could offer practical opportunities for reducing the impact of recreational uses through spatial planning techniques (e.g., confining disturbance activities to less utilised parts of the beach). These studies are being done at three focus sites (Ward Beach, Canterbury Gully and Airstrip Beach) and involve a community 'citizen science' component to help locate and record the exact position of nests on the beach.

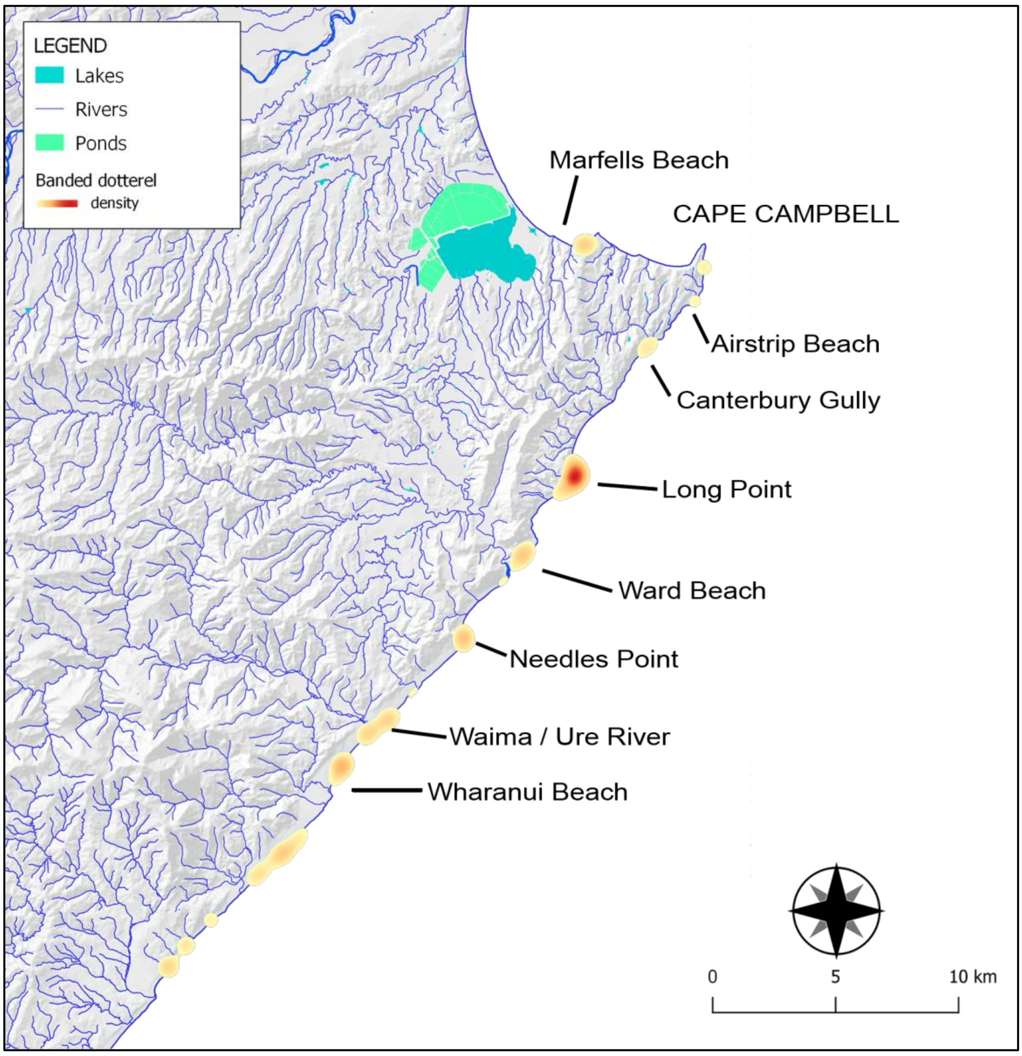

Fig. 4.18 Visualisation of spatial density for banded dotterel (*Charadrius bicinctus bicinctus)* nesting 'hotspots' in 2018. This survey included the coastline south to Kaikōura and the northern limit was Marfells Beach.

4.5 Recreational activities and vehicle tracking

4.5.1 Recreational activities and access points

Field observations over the summers of 2018 and 2019 showed a surprisingly wide range of powered and non-powered access modes. These include walking, horse riding, and a variety of ORVs including trail bikes, quad bikes and larger 4WD vehicles. Important recreational interest groups include local fishers and crayfishers, many of whom have a long association with area. Many fishers access the coast using quad bikes targeting lower tides, and are accustomed to hauling the equipment required for using fixed methods such as craypotting. Dive-related activities were adversely affected by the earthquake due to a combination of habitat depletion, increased turbidity and closure of the pāua fishery, all of which are influenced by the widespread die-off of kelp beds in the area (Alestra et al. 2019; Schiel et al. 2019). These activities can be expected to become increasingly important in the future, pending the recovery of coastal habitats and fish/shellfish stocks.

4.5.2 Vehicle tracking

Since the earthquake uplift, vehicle traffic has increased in many sections of the Marlborough coastline. Stretches of beach that were virtually inaccessible can now be accessed across most of the tidal cycle. Our initial surveys focussed on vehicle tracking patterns as an indicator of potential impact due to the importance of spatial overlaps with vegetation recovery (e.g., dune system formation), and wildlife (e.g., shorebird nesting sites). The pattern of recreational access originates from several well-defined access points because of the relatively scarcity of public roads leading to the coast. Access to the Cape Campbell area is primarily from the north via Marfells beach, which provides firm sand conditions at most tides. Prior to the earthquake, a section of steep ground at Mussel Point deterred most forms of ORV traffic from travelling further around the coast. Closer to Cape Campbell, many of the navigable beaches were narrow or non-existent at high tide, so there was only a narrow window of opportunity for ORV use around low tide. Vehicles can now travel south from Marfells Beach as far as Chancet Rocks, conditions permitting. Other established access points at Ward Beach and from the Waima / Ure river mouth remain popular, the result being that only small sections of the coastline around the Needles and at Chancet Rocks are free from ORV disturbance.

Tracking width and access point surveys completed to date show that more than 50% of the high tide beach width is used by ORVs in many areas. The tracking pattern shows no clear preference for route choice at many sites, resulting in larger affected areas with a lower frequency of disturbance compared to situations where there is a defined vehicle track (Fig. 4.19). This is consistent with the wide variety of vehicles being used, each of which has a degree of association with different recreational objectives and environmental conditions.

Fig. 4.19 Vehicle tracking patterns on the Marlborough coast. (a) off-road vehicle (ORV) tracking on the high tide beaches south of Cape Campbell features extensive areas of wandering tracks with no defined vehicle route. (b) powered and non-powered access modes are popular on the north facing beaches near Mussel Point. Although most of the ORV tracking in this area occurs in the intertidal range, some vehicle types (e.g., quads and buggies) have also been observed on the high tide beach and dune face.

Based on repeat surveys of 120 monitoring points distributed between Kekerengu and Marfells Beach, the average tracking width increased slightly from 13 m in 2018 to 15 m in 2019. The maximum tracking width recorded was 60 m in the vicinity of the Waima / Ure river mouth (Fig. 4.20) and little change was noted between years. This is a popular area for ORV access and features wide expanses of gravel beach and riverbed associated with a river mouth lagoon. ORV use is also prominent to the south towards Wharanui Beach and north towards Needles Point, which appears to be a popular destination based on turnaround tracking patterns at the northern end of the beach. Other areas with relatively large areas of tracking on the high tide beach include Long Point, where the presence of rocky reefs in the intertidal zone appears to have forced ORV traffic onto the high tide beach, and on the pea-gravel beaches between Cape Campbell and Canterbury Gully where similar effects exist. There is also a small area of extensive tracking at Ward Beach (Fig. 4.20).

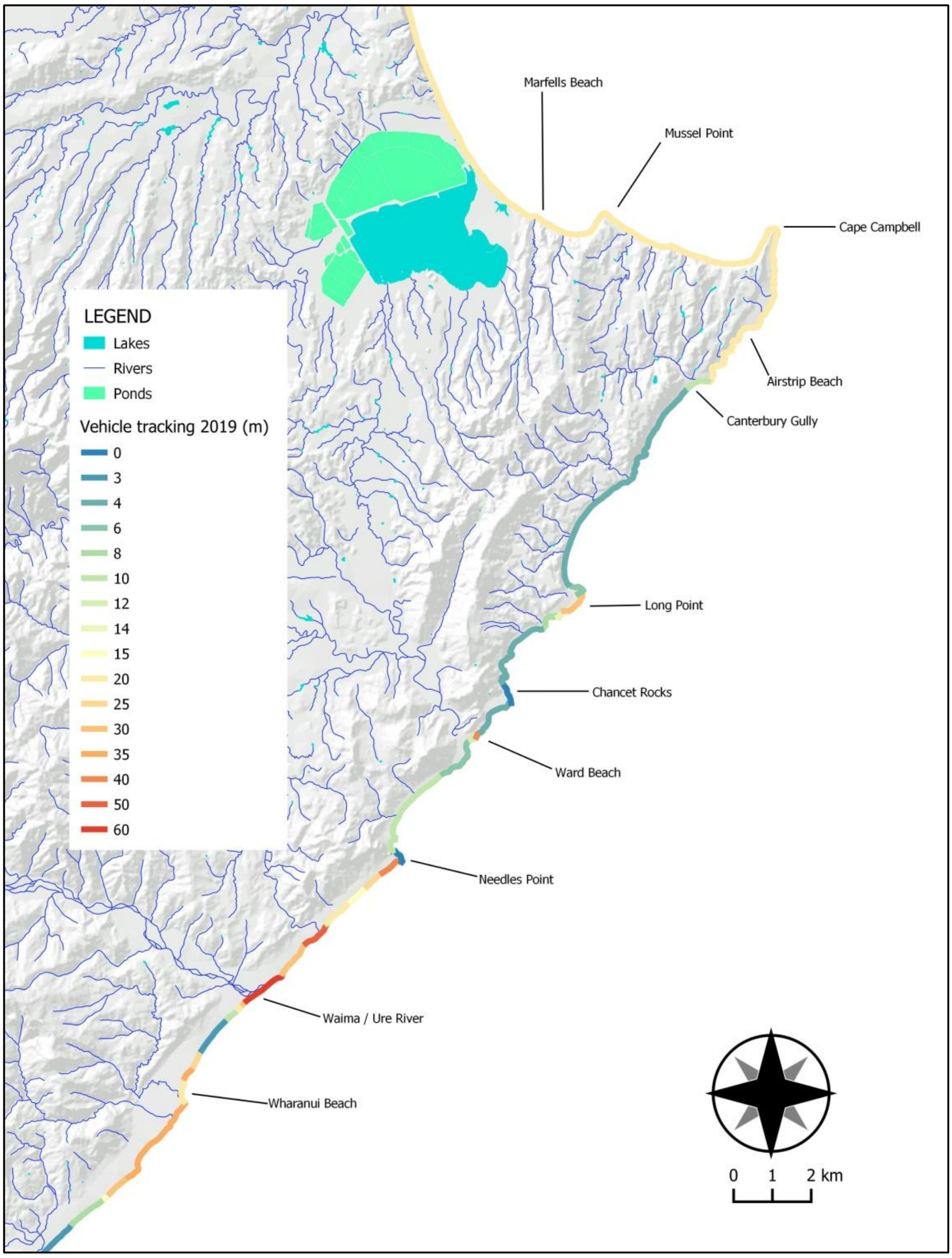

Fig. 4.20 Width of vehicle tracks recorded on Marlborough beaches above the post-earthquake high tide mark in the summer of 2019.

These observations also indicate that additional tracking occurs below the high tide mark in many sections of the coast, particular where wide dissipative beaches are present. Although the methodology used here does not directly detect these patterns they can be deduced from the tracking observed on sequential sections of high tide beach following the direction of vehicle movement from the known access points.

These observations clearly show the following patterns:

- extensive vehicle tracking is present between the Waima / Ure River and Needles Point. A 400 m section of rocky coast at Needles Point produces an effective barrier to further ORV travel to the north from the Waima / Ure access point.
- south of the Ward Beach access point there is a relatively low level of tracking (typically 2-3 vehicle tracks) as far as the abovementioned barrier at Needles Point, indicative of regular local users (e.g. ,fishermen) accessing this section of coast.
- north of the Ward Beach access point there is a relatively low level of tracking (typically 1-2 vehicle tracks) north to Chancet Rocks and similar levels (2-3 tracks) on the beaches further north followed by a marked change at the rocky headland immediately south of Long Point. This is considered to represent a popular turnaround point (potential destination) for ORV traffic travelling south from the Cape Campbell area. Since Chancet Rocks present a barrier to most ORVs, these patterns suggest lower traffic volumes south of Long Point that are probably associated with regular local users in that area. In comparison, a wide range of vehicle types have been observed north of Long Point and there is much more extensive tracking between here and Marfells Beach. This is considered to represent southward-travelling ORVs that have come around Cape Campbell from the north, although the observed patterns may be influenced by a small number of additional access points (e.g., vehicle owners who are able to access the area through private land). Apparent 'gaps' in vehicle tracking on the high tide beach in this section of coast (Fig. 4.20) are mainly due to the presence of firm sand sections within the intertidal range which provide convenient travel options on lower tides. These sections include the large sandy bay south of Canterbury Gully in the vicinity of Booboo Stream as well as the sandy beaches at Marfells and Mussel Point.

4.5.3 Future research and information gaps

It is important to note that the measurements reported here are affected to some degree by the periodic effects of 'reset' events such as storms that can wipe away visible signs. In general, these have been infrequent over the study period to date, although there are effects of wind-erosion, sand movement and reworking of beaches by wave action during large swells. These effects are likely to be variable between sites. In the present study they are considered to have primarily resulted in an underestimation of tracking at sandy beach sites in comparison to the pea-gravel beaches, which seem to have been relatively stable over the study period. In the future, finer scale measurements of vehicle tracking and movements would be useful to assess specific impacts on different parts of the beach, including the frequency of vehicle movements in different areas. The latter cannot be accurately estimated using the visual clues reported here, despite the presence of some useful indicators such as the ability to identify individual vehicles where tracking is relatively sparse, and the development of well-worn tracks.

4.6 Assessment of recreational impacts

To help assess the potential for adverse impacts associated with recreational activities and other post-quake land uses the RECOVER project has been quantifying the spatial footprint of important ecological values in the post-earthquake environment. This information is needed to evaluate the degree of spatio-temporal overlap with potential threats, helping to ensure that adverse impacts are detected and ideally avoided. A better understanding of the spatial attributes of recreational activities and access modes is also required to evaluate their interactions with natural environment recovery and associated natural resources.

With regards to ORV activities, driver education may play an important role in this respect since the current landscape is relatively barren and it is difficult to detect the location of sensitive ecological zones using visual clues due to the severity of earthquake impacts and prolonged nature of recovery trajectories. New vegetation and other signs of life are only gradually reappearing. Therefore, there is an interaction between perceptions of the post-earthquake environment and its potential for recovery that is mediated by influences on recreational choices. Improving public awareness of the post-quake environment and its recovery needs could provide a useful focus in support of voluntary behaviours that can help reduce impacts and avoid trade-offs. The same approach will also be useful to build public buy-in for formal protection measures.

4.6.1 Uplift effects on the shore profile

Earthquake uplift has largely facilitated the expansion of access opportunities through the creation of high tide beaches in the former intertidal range. At other beaches, it has introduced new supratidal zones such as terraces and dunes that represent new habitats due to characteristics such as driftwood sequestration, vegetation growth and associated wildlife movement (Fig. 4.21). These wider beach profiles also open up additional possibilities for access routes that include opportunities to avoid sensitive or unstable areas. This provides a mechanism to reduce impacts through route selection provided that the protected areas can be effectively identified and communicated to recreational groups and interests.

Related research on changes to reef platforms has shown high ongoing rates of substrate erosion in the new intertidal range, with the highest rates being found on the exposed south-facing coastline between Long Point and Cape Campbell due to their combination of uplift and soft mudstone substrates. The wetting and drying cycle of these uplifted platforms results in tension cracks that are exposed to wave action, and subsequent wind and water action on these brittle surfaces results in the erosion of rock layers. At many sites, these layers typically range from around 1 cm to five or more centimetres in thickness (Fig. 4.21c, d). Field measurements have recorded an ongoing cycle of development and shedding of these layers that includes periods of rapid surface loss that poses a major impediment to the establishment of vegetation. These responses suggest that reef weathering may continue until lower elevations are reached, with stabilisation of the shore platform as drying times decrease, and assistance from revegetation processes. Many of these uplifted reef platforms are now more easily accessed by foot and motorised vehicles, potentially affecting erosion rates even with a relatively low volume of traffic due to the instability of the substrate. However, the management of disturbance impacts may become even more critical once physical erosion rates reduce and intertidal algal-based ecosystems begin to recover. In combinations, these changes to the shore profile coincide with new interactions between people and the environment.

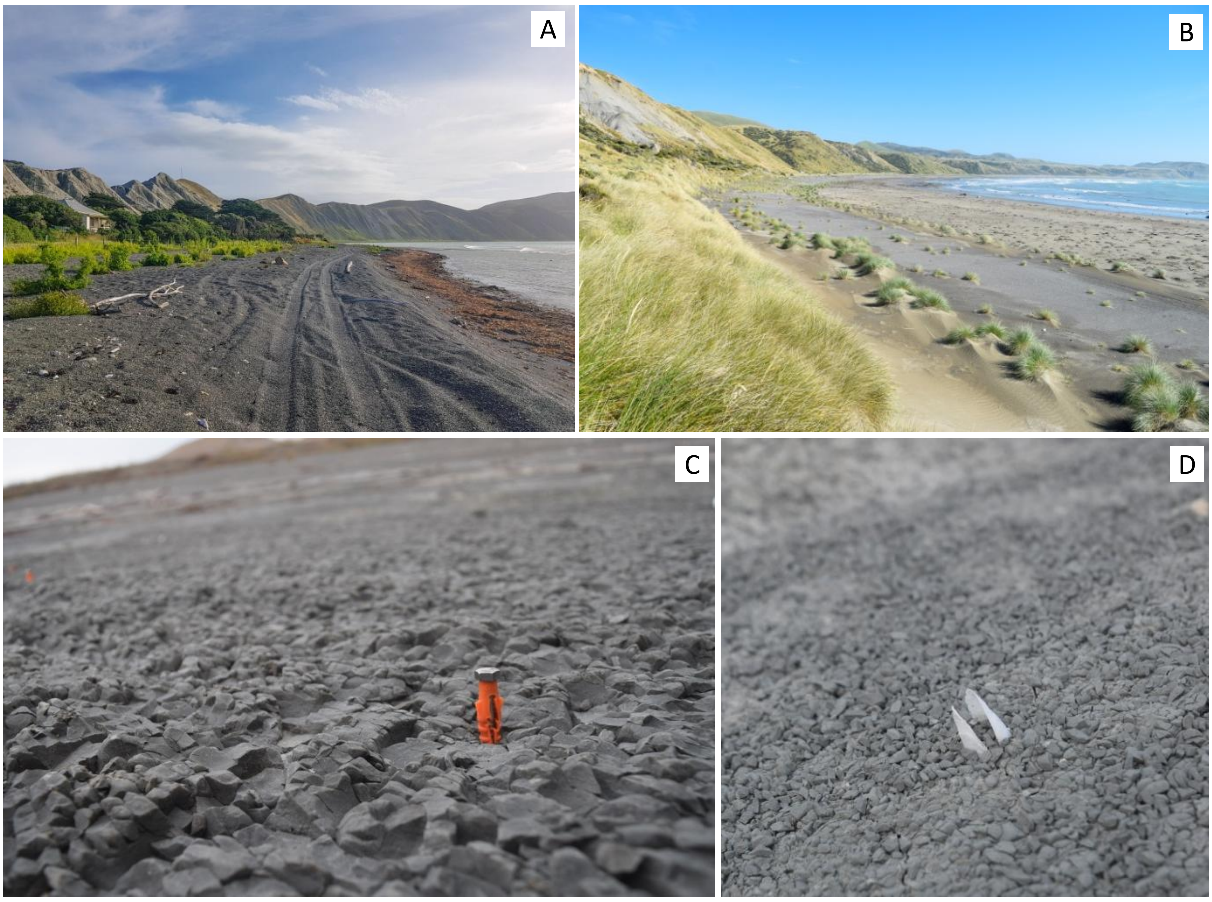

Fig. 4.21 Effects of earthquake uplift. (a) expansion of the high tide beach at Cape Campbell has been sufficient to permit vehicle access on most tides. (b) widening of beaches north of Long Point that has been associated with the formation of new lines of dunes and driftwood zones on the uplifted beach. (c) reef weathering studies have recorded the ongoing erosion of soft mudstone substrates associated with the shedding of brittle surface layers as shown here at monitoring site (Gate Reef) south of Cape Campbell (d) the shells of burrowing bivalves that once lived in holes bored into the substrate are now stark indicators of reef erosion trends.

4.6.2 Spatial overlaps between sensitive areas and recreational uses

This section provides a brief summary of the spatial distribution of three ecological values that we have studied (dune vegetation, katipō habitat and banded dotterel nesting sites) in relation to ORV tracking on the uplifted high tide beaches. It is important to note that this only represents a subset of the potential impacts of recreational uses on ecological recovery since there is a wide range of other sensitive species and habitats present (for example, shellfish and other in-fauna on sandy beaches). In addition, this information provides only an indication of the potential for adverse impacts due to its focus on the co-occurrence of largely incompatible activities such as the use of beaches by ORV use and successful shorebird nesting. Further information on temporal aspects (e.g., frequency and timing of disturbances) in relation to the values of interest (e.g., clutch survival rate for banded dotterel) is needed for a comprehensive assessment of impacts. Nonetheless, these preliminary analyses can help to identify options for the avoidance of potential impacts through techniques that separate the footprints of incompatible activities (e.g., as may be communicated in bylaws, voluntary codes and other forms of spatial planning).

Dune vegetation

The information presented in section 4.2 shows marked differences in the responses of pre-quake dune systems to earthquake uplift. These differences result from a combination of factors that include differential degrees of uplift, composition of the pre-quake dune system, and proximity of seed sources.

With regards to the conservation of indigenous dune systems that are the subject of statutory protection, the occurrence of new recruits that are forming ‘new dunes’ and the extension of runners from existing spinifex and pīngao remnants, are both important processes. When overlaid with the ORV tracking data, a highly site-specific pattern of potential impacts emerges.

For example, at Mussel Point, both new recruits and runner extension from spinifex remnants is occurring but the ‘new dune’ resulting from a combination of both is relatively small (e.g. 10- 15 m in width). In theory, it should be relatively straightforward for recreational users to identify and avoid this area. At Aerial Beach, the new dune zone is formed entirely by new recruits within an area that is a considerable distance (e.g. 20 - 30 m) seaward of the old-dune toe. As a consequence the ‘new dune’ zone is a currently a band of vegetation seaward of the old dune system. Unlike Mussel Point, potential ORV routes include the ‘gap’ between the old dune toe and newly forming dune as well as travel on firmer sands lower on the beach within the intertidal range. The specific impacts of these various options require further assessment in relation to the newly establishing dune zone but also other considerations.

At Long Point, there has been very little evidence of new spinifex recruitment at the study site even though important recruitment areas were recorded on sandy beaches nearby. This can be mainly attributed to the specific nature of the uplifted beach at this location, which is a characterised by mixed sand-gravel substrates and a relatively steep profile. Uplift effects on the spinifex dune remnants in this area include new space for the seaward extension of runners from existing remnants at the old dune toe, with the new recruitment zone being less important. Therefore, a relatively modest exclusion area to reduce or prevent ORV impacts on the upper beach near the dune toe could prove effective for post-earthquake dune conservation in this area.

The main take-away messages from these spatial patterns include the need to avoid driving on existing dune faces, particularly where spinifex and/or pīngao are present, and the need to avoid disturbance to the new recruitment zone where new dunes are establishing. Spatial variability in the pattern of dune responses suggests that site-specific approaches are important, and this is important to keep in mind for the development of both regulatory and non-regulatory approaches to beach management and in the design of communication materials.

Katipō habitat

Results from the katipō pilot study show little overlap between the current location of important habitat and incompatible recreational use with the exception of some ORV use that is occurring within remnant spinifex dunes. However, this study has been primary conducted to inform longer term considerations associated with the potential seaward movement of fore-dunes, with potentially important implications for katipō. The preliminary understanding we have gained from the pilot study indicates that these effects are likely due to the observation of higher katipō densities in exposed fore-dune habitats and in sparse vegetation types in particular. These results indicate a potential for katipō movement into newly developing areas of dunes that are forming on uplifted surfaces through both new recruitment and the vegetative expansion of spinifex remnants (involving the seaward extension of runners). This context has positive opportunistic implications for the conservation of katipō through the potential to create new areas of favourable habitat in uplifted area.

Conversely, there is also the potential for older (pre-earthquake) dunes to stabilise under the influence of a reduction in sand supply that is likely to be associated with the blocking effect of new fore-dunes developing to seaward. Under these circumstances, existing areas of favourable habitat could become less suitable due to processes such as invasion by marram or pasture grasses which have the potential to increase vegetation density. The balance between these processes is therefore of particular interest and is recommended for long term monitoring.

The objective of upcoming research with the RECOVER project (in the summer of 2021) will be to establish a baseline survey design and associated measurements. However, this will be insufficient to follow the important changes, which are expected to be progressive in nature and continued well beyond the timeline of the RECOVER project. These changes are directly relevant to post-earthquake beach management since they will influence the location and extent of important katipō habitat.

Banded dotterel nesting sites

Results from the whole-coast census surveys show well-defined hotspots with clusters of nesting sites in close proximity. This provides useful information for delineating sensitive areas for protection in appropriate ways. To determine larger-scale priorities, the relative importance of these different areas can be assessed according to criteria such as spatiotemporal abundance, nest productivity and survival rates. Prioritisation criteria can also be applied to discrete areas to provide decision-support for stakeholders, for example by enabling stakeholders to test the outcomes of different planning options.

At the cross-shore scale, we currently have limited information on the relative importance of different areas. In the 2021 summer three mixed sand-gravel beach study sites are being monitored with the help of interested community members to determine banded dotterel nesting intensity in relation to tidal and supratidal zones. This information will help to identify the degree of hazard posed by ORVs in different elevation zones by evaluating the overlap with dotterel nesting sites.

Additionally, the nearshore zonation pattern has changed markedly since the earthquakes and many of our longer term studies are quantifying these changes. In uplifted areas many beaches have widened considerably. A particular question for shorebird conservation concerns the degree to which newly exposed substrates have increased the potentially suitable area for shorebird nesting. To address this, there is also a need to consider the longer term effects of revegetation processes within areas of 'new land'. These are incorporated within the RECOVER project in relation to 'recovery trajectories' and require temporal changes to be followed over a period of time to ascertain the likely outcomes.

In the longer term, outcomes of the earthquake may include the revegetation of land that has become exposed and become newly available from a combination of physical uplift and the widespread mortality of previously habitat-forming species. Ascertaining these effects on shorebird nesting success is therefore as important to the concept of earthquake impacts. This requires evaluation alongside the influence of ORVs and other contemporary disturbance events such as natural hazards.

5 Summary of key findings

5.1 Decline of pīngao

Results from the comprehensive surveys of pīngao remnants and recruits provide strong evidence for recent pīngao mortality that is indicative of an ongoing trend. This should be of concern to coastal managers given the current conservation status of pīngao as an 'at risk – declining' species in the New Zealand Threat Classification System (de Lange et al. 2018) and as a Ngāi Tahu taonga species (New Zealand Government 1998; Te Rūnanga o Ngāi Tahu 2014). The overall pattern includes an apparent lack of recruitment to replace old-dune pīngao remnants that are under threat from environmental changes. Addressing this requires a focus on both the resilience and vulnerability of old-dune remnants and a better understanding of new recruitment.

5.2 Potential for opportunistic dune restoration

A limited amount of spinifex recruitment has been observed in the post-earthquake landscape following a highly specific spatial pattern. This pattern is indicative of a strong influence from existing seed sources in combination with prevailing wind directions. The discovery of large gaps in the pattern of recruitment is one of the notable consequences of these effects, whilst at the same time there is theoretically an abundance of new potential habitat for dune ecosystems that has been created through earthquake uplift. Importantly, this unoccupied space is currently free from one of the primary causes of indigenous dune system loss in New Zealand, being the establishment of invasive marram (Hilton et al. 2000; Hilton 2006). This gives rise to a unique opportunity to re-establish spinifex dune ecosystems through strategic restoration approaches. This is the subject of further research under the auspices of the Beach Aid project in collaboration with MDC, DOC and ECPG.

The key innovation behind Beach Aid is the implementation of a restoration strategy that aims to re-establish seed sources for native sand binders at prominent gaps in their current distribution. This opportunistic approach takes advantage of the improved understanding of spatial dune ecology derived from the studies described here, and the new accommodation space for dune establishment that has been generated by the earthquake. Although the initial focus and trial are directed towards spinifex, the same approach could readily be explored in relation to pīngao and is recommended for consideration.

Coastal succession and zonation processes will be important to the longer-term disaster recovery outcomes in many uplifted areas. Revegetation processes are likely to have a stabilising effect and are an important focus for monitoring, with the response of habitat-forming species being particularly important.

5.3 Conservation of katipō on uplifted beaches

The pilot study reported here contributes to the understanding of the Marlborough coast as an important location for katipō, as reported in previous studies (Anderson & Anderson 2019; Patrick 2002). The results help to characterise some important aspects of spatial ecology that are directly relevant to coastal management and may differ from patterns observed elsewhere. In particular, the spatially-explicit measures used in these surveys show the importance of the fore-dune face for katipō habitat, and indicate that this should be a focus for conservation efforts.

These results also support the findings of previous studies regarding the negative impact of dense marram grass on the availability of suitable habitat, reinforcing the conclusions of several authors on the need for marram control to support katipō conservation (Costall & Death 2009; Griffiths 2001; Patrick 2002; Smith et al. 2014). This lends additional weight to the rationale for strategic interventions to re-establish indigenous dune systems on the earthquake-affected coast through Beach Aid initiatives that have the potential to reverse decades of previous degradation. However, regardless of these potential restoration interventions, results from the pilot study indicate that 'new dune' zones on uplifted beaches have the potential to provide katipō habitat. This suggests that the continued development and condition of these new habitats is important to monitor into the future. An additional unknown aspect involves the potential for displacement effects that could be driven by the stabilisation of older dunes (i.e., landward of the new dunes that are forming on the uplifted beaches), since these conditions may promote the establishment of dense marram stands or other unfavourable species.

Lastly, the spatial variation observed between study sites suggests that currently unknown factors are also important influences on the wider katipō distribution. These may represent legacy effects associated with habitat fragmentation or simply artefacts of the limited spatial coverage that has been possible in surveys to date. A better understanding of these aspects will be the subject of further research over the 2020 summer, and has the potential to generate additional insights on the population structure (e.g., identification of important areas and existence of gaps), that will help to inform coastal management and restoration strategies.

5.4 Protection of shorebird nesting habitat

Relatively consistent results over two summers show the existence of hotspots in the spatial distribution of banded dotterel nesting territories. These areas provide an initial focus for protection and are priorities for monitoring. These hotpots occur on both sandy and mixed-sand gravel beaches. Our current information suggests a considerable degree of overlap between nesting sites and the post-quake vehicle tracking pattern in these areas. Therefore, it may be beneficial to reduce or relocate vehicle movements to avoid these areas during the nesting period.

Further work is needed to determine the relative importance of different zones within the cross-shore profile of uplifted beaches, and this provides useful information on the specific impacts of vehicle movements. The beach profile in these areas has changed markedly since the earthquake and has the potential to provide new space for some habitats and ecosystems. At the same time, the re-arrangement process creates opportunities to improve integration with human activities. Finer scale information on spatial patterns such as the degree of conflict between different land-uses will be useful to help identify these opportunities.

Although banded dotterel have been the focus of our studies to date, similar considerations could be investigated in relation to the breeding habitat of other species. Disturbance effects on shorebird roosting and feeding habitat have also been reported and these introduce a further set of considerations that are relevant to the assessment of ORV impacts and their management (Weston et al. 2014; Zharikov & Milton 2009). Over the longer term, there is potential for outcomes to vary considerably and also potential for positive interventions.

5.5 Assessing change across multiple scales

Within the RECOVER project we are applying a suite of techniques to improve the understanding of change across multiple scales for a selection of important values. The data collection methods include various forms of remote sensing as well as field surveys and experiments that aim to cover as much of the spatio-temporal variation as possible across a relatively large study area. In general, information on finer-scale patterns related to earthquake changes and recovery processes are very useful for the assessment and mitigation of impacts but require greater resources to acquire. However, bringing together the results of studies at a variety of scales is needed for a comprehensive understanding of change and to assess the merits of new management proposals. These needs will continue beyond the life of the RECOVER project since many important recovery processes are only just beginning (e.g., new dune establishment and kelp forest recovery). At the same time, ongoing disturbances including natural disasters and climate change will continue to affect the coast and are an important focus for longer term monitoring.

6 Acknowledgements

Funding for the RECOVER project was provided by the New Zealand Ministry of Business, Innovation and Employment (MBIE), and the Ministry for Primary Industries (MPI). We also thank Marlborough District Council for the opportunity to provide this report. The research projects reported here have also benefited from helpful conservations with MDC staff as well as inputs from a wide range of other organisations. Particular thanks to local landowners and community members who have assisted with establishment of the RECOVER study sites or who are directly involved in some of the collaborative research and restoration projects.

7 References

Alestra, T., Gerrity, S., Dunmore, R., Marsden, I., Pirker, J., & Schiel, D. (2019). *Rocky reef impacts of the Kaikōura earthquake: quantification and monitoring of nearshore habitats and communities. New Zealand Aquatic Environment and Biodiversity Report No. 212*. Report prepared for Fisheries New Zealand. 120pp.

Anderson, M., & Anderson, E. (2019). *The katipō (Latrodectus katipō) population of Marlborough's eastern coast*. Unpublished report prepared for the Marlborough community. 10 pp. .

Brunton, P. M. (1978). Toheroa predation by black-backed gulls on Dargaville beach, North Auckland, New Zealand. *Notornis, 25*(2), 128-140.

Clark, K. J., Nissen, E. K., Howarth, J. D., Hamling, I. J., Mountjoy, J. J., Ries, W. F., . . . Strong, D. T. (2017). Highly variable coastal deformation in the 2016 MW7.8 Kaikōura earthquake reflects rupture complexity along a transpressional plate boundary. *Earth and Planetary Science Letters, 474*, 334-344. doi:10.1016/j.epsl.2017.06.048

Costall, J. A., & Death, R. G. (2009). Population structure and habitat use by the spider Latrodectus katipo along the Manawatu-Wanganui coastline. *New Zealand Journal of Zoology, 36*(4), 407-415. doi:10.1080/03014223.2009.9651473

Costall, J. A., & Death, R. G. (2010). Population monitoring of the endangered New Zealand spider, Latrodectus katipo, with artificial cover objects. *New Zealand Journal of Ecology, 34*(2), 253-258.

Davenport, J., & Davenport, J. L. (2006). The impact of tourism and personal leisure transport on coastal environments: A review. *Estuarine, Coastal and Shelf Science, 67*(1-2), 280-292. doi:10.1016/j.ecss.2005.11.026

Davies, R., Speldewinde, P. C., & Stewart, B. A. (2016). Low level off-road vehicle (ORV) traffic negatively impacts macroinvertebrate assemblages at sandy beaches in south-western Australia. *Scientific reports, 6*(1), 24899. doi:10.1038/srep24899

de Lange, P., Rolfe, J. R., Courtney, S. P., Barkla, J. W., Champion, P. D., Perrie, L. R., . . . Ladley, K. (2018). *Conservation status of New Zealand indigenous vascular plants, 2017. New Zealand Threat Classification Series 22*. Wellington: Department of Conservation. 82 pp.

Defeo, O., McLachlan, A., Schoeman, D. S., Schlacher, T. A., Dugan, J., Jones, A., . . . Scapini, F. (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science, 81*(1), 1-12. doi:10.1016/j.ecss.2008.09.022

Forster, L., & Kingsford, S. (1983). A preliminary study of development in two Latrodectus species (Araneae: Theridiidae). *New Zealand Entomologist, 7*(4), 431-439. doi:10.1080/00779962.1983.9722437

Forster, R. R., & Forster, L. M. (1973). *New Zealand spiders: an introduction*. Auckland: Collins.

Griffiths, J. W. (2001). *Web site characteristics, dispersal and species status of New Zealand's katipo spiders, Latrodectus katipo and L. atritus*. Unpublished PhD thesis, Lincoln University, New Zealand. 91 pp.

Groom, J. D., McKinney, L. B., Ball, L. C., & Winchell, C. S. (2007). Quantifying off-highway vehicle impacts on density and survival of a threatened dune-endemic plant. *Biological Conservation, 135*(1), 119-134. doi:10.1016/j.biocon.2006.10.005

Hamling, I. J., Hreinsdóttir, S., Clark, K., Elliott, J., Liang, C., Fielding, E., . . . Stirling, M. (2017a). Complex multifault rupture during the 2016 Mw 7.8 Kaikoura earthquake, New Zealand. *Science, 356*(6334). doi:10.1126/science.aam7194

Hamling, I. J., Hreinsdóttir, S., Clark, K., Elliott, J., Liang, C., Fielding, E., . . . Stirling, M. (2017b). Complex multifault rupture during the 2016 M w 7.8 Kaikōura earthquake, New Zealand. *Science (American Association for the Advancement of Science), 356*(6334), eaam7194. doi:10.1126/science.aam7194

Hann, S. W. (1990). Evidence for the displacement of an endemic New Zealand spider, Latrodectus katipo Powell by the South African species Steatoda capensis Hann (Araneae: Theridiidae). *New Zealand Journal of Zoology, 17*(3), 295-307. doi:10.1080/03014223.1990.10422937

Hilton, M., MacAuley, U., & Henderson, R. (2000). *Inventory of New Zealand's active dunelands*. Science for Conservation 157. Department of Conservation. Wellington.

Hilton, M. J. (2006). The loss of New Zealand's active dunes and the spread of marram grass (Ammophila arenaria). *New Zealand Geographer, 62*(2), 105-120. doi:10.1111/j.1745-7939.2006.00054.x

Holden, C., Kaneko, Y., D'Anastasio, E., Benites, R., Fry, B., & Hamling, I. J. (2017). The 2016 Kaikōura Earthquake Revealed by Kinematic Source Inversion and Seismic Wavefield Simulations: Slow Rupture Propagation on a Geometrically Complex Crustal Fault Network. *Geophysical Research Letters, 44*(22), 11,320-311,328. doi:10.1002/2017GL075301

Hooker, S., & Readfearn, P. (1998). *Preliminary survey of toheroa (Paphies ventricosa) populations on Ninety Mile Beach and possible impacts of vehicle traffic*. Report prepared for the Northland Regional Council. 32 pp.

Hosier, P. E., & Eaton, T. E. (1980). The Impact of vehicles on dune and grassland vegetation on a south-eastern North Carolina barrier beach. *The Journal of applied ecology, 17*(1), 173-182. doi:10.2307/2402972

Houser, C., Labude, B., Haider, L., & Weymer, B. (2013). Impacts of driving on the beach: Case studies from Assateague Island and Padre Island National Seashores. *Ocean & Coastal Management, 71*, 33-45. doi:10.1016/j.ocecoaman.2012.09.012

Jiang, Z., Huang, D., Yuan, L., Hassan, A., Zhang, L., & Yang, Z. (2018). Coseismic and postseismic deformation associated with the 2016 Mw 7.8 Kaikoura earthquake, New Zealand: fault movement investigation and seismic hazard analysis. *Earth, Planets and Space, 70*(1), 1-14. doi:10.1186/s40623-018-0827-3

Kapiti Coast District Council. (2009). *Kapiti Coast District Council Beach Bylaw 2009*. Kapiti Coast District Council. Retreived 12 August 2020 from www.kapiticoast.govt.nz/media/21960/beach-bylaw-2009-amended-2017.pdf.

Lilley, S. A., & Schiel, D. R. (2006). Community effects following the deletion of a habitat-forming alga from rocky marine shores. *Oecologia, 148*(4), 672-681. doi:10.1007/s00442-006-0411-6

Marlborough District Council. (2019a). *Marlborough's East Coast - Issues and Options*. Report prepared by Marlborough District Council, November 2019. 48 pp.

Marlborough District Council. (2019b). *Marlborough's East Coast - Technical report*. Report perpared by Marlborough District Council, 22 March 2019. 57 pp.

Moller, J. A., Garden, C., Moller, S. I., Beentjes, M., Skerrett, M., Scott, D., . . . Moller, H. (2014). *Impact of vehicles on recruitment of toheroa on Oreti Beach*. Report prepared for Te Ao Mārama, Environment Southland, Invercargill City Council and Department of Conservation. 79 pp.

New Zealand Government. (1998). *Ngāi Tahu Claims Settlement Act 1998. Reprint as at 1 August 2020*. Wellington: New Zealand Government.

Norbury, G., & Heyward, R. (2008). Predictors of clutch predation of a globally significant avifauna in New Zealand's braided river ecosystems. *Animal Conservation, 11*(1), 17-25. doi:10.1111/j.1469-1795.2007.00142.x

Orchard, S., Hughey, K. F. D., Measures, R., & Schiel, D. R. (2020a). Coastal tectonics and habitat squeeze: response of a tidal lagoon to co-seismic sea-level change. *Natural Hazards, 103*(3), 3609-3631. doi:10.1007/s11069-020-04147-w

Orchard, S., Hughey, K. F. D., & Schiel, D. R. (2020b). Risk factors for the conservation of saltmarsh vegetation and blue carbon revealed by earthquake-induced sea-level rise. *Science of the Total Environment, 746*, 141241. doi:10.1016/j.scitotenv.2020.141241

Ota, Y., Pillans, B., Berryman, K., Beu, A., Fujimori, T., Miyauchi, T., . . . Climo, F. M. (1996). Pleistocene coastal terraces of Kaikoura Peninsula and the Marlborough coast, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics, 39*(1), 51-73. doi:10.1080/00288306.1996.9514694

Patrick, B. (2002). *Conservation status of the New Zealand red katipo spider (Latrodectus katipo Powell, 1871). Science for Conservation 194.* . Wellington: Department of Conservation. 33 pp.

Priskin, J. (2003). Physical impacts of four-wheel drive related tourism and recreation in a semi-arid, natural coastal environment. *Ocean and Coastal Management, 46*(1), 127-155. doi:10.1016/S0964-5691(02)00124-2

Schiel, D. R., & Taylor, D. I. (1999). Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *Journal of Experimental Marine Biology and Ecology, 235*, 213-235.

Schiel, D. R., Gerrity, S., Alestra, T., Pirker, J., Marsden, I., Dunmore, R., . . . Thomsen, M. (2018). *Kaikōura earthquake: Summary o1f impacts and changes in nearshore marine communities*. In (Hendlass, C. Borrero, J., Neale, D., and Shand, T. (eds). Shaky Shores: coastal impacts & responses to the 2016 Kaikōura earthquakes. New Zealand Coastal Society, Special Publication 3, 2018, 44 pp.

Schiel, D. R., Alestra, T., Gerrity, S., Orchard, S., Dunmore, R., Pirker, J., . . . Thomsen, M. (2019). The Kaikōura earthquake in southern New Zealand: Loss of connectivity of marine communities and the necessity of a cross-ecosystem perspective. *Aquatic Conservation: Marine and Freshwater Ecosystems, 29*(9), 1520-1534. doi:10.1002/aqc.3122

Schlacher, T. A., Dugan, J., Schoeman, D. S., Lastra, M., Jones, A., Scapini, F., . . . Defeo, O. (2007). Sandy beaches at the brink. *Diversity and Distributions, 13*(5), 556-560. doi:10.1111/j.1472-4642.2007.00363.x

Schlacher, T. A., & Thompson, L. M. C. (2007). Exposure of fauna to off-road vehicle (ORV) traffic on sandy beaches. *Coastal Management, 35*(5), 567-583. doi:10.1080/08920750701593402

Schlacher, T. A., Richardson, D., & McLean, I. (2008). Impacts of off-road vehicles (ORVs) on macrobenthic assemblages on sandy beaches. *Environmental management (New York), 41*(6), 878-892. doi:10.1007/s00267-008-9071-0

Sirvid, P. J., Vink, C. J., Wakelin, M. D., Fitzgerald, B. M., Hitchmough, R. A., & Stringer, I. A. N. (2012). The conservation status of New Zealand Araneae. *New Zealand Entomologist, 35*(2), 85-90. doi:10.1080/00779962.2012.686310

Smith, V. R., Vink, C. J., Nager, R. G., Ross, J., & Paterson, A. M. (2014). Abundance of Latrodectus katipo Powell, 1871 is affected by vegetation type and season. *Journal of Insect Conservation, 18*(3), 397-405. doi:10.1007/s10841-014-9648-2

Stephenson, G. (1999). *Vehicle impacts on the biota of sandy beaches and coastal dunes: A review from a New Zealand perspective. Science for Conservation 121*. Wellington: Department of Conservation. 48 pp.

Tait, L. W., & Schiel, D. R. (2011). Legacy effects of canopy disturbance on ecosystem functioning in macroalgal assemblages. *PLoS One, 6*(10). doi:10.1371/journal.pone.0026986

Tauranga City Council. (2018). *Beaches Bylaw*. Tauranga City Council. Retrieved 12 August 2020 from https://www.tauranga.govt.nz/Portals/0/data/council/bylaws/files/beaches_bylaw_2018.pdf.

Taylor, G. F., Marsden, I. F., & Hart, D. E. (2012). *Management of vehicle and horse users on sand beaches: Implications for shellfish populations*. Report prepared for the Canterbury Regional Council. 56 pp.

Te Rūnanga o Ngāi Tahu. (2014). *Pīngao – A taonga*. Ōtautahi Christchurch: Te Rūnanga o Ngāi Tahu. Retrieved 25 August 2020 from https://ngaitahu.iwi.nz/our_stories/pingao-taonga/.

Waimakariri District Council. (2016). *Northern Pegasus Bay Bylaw 2016*. Waimakariri District Council. Retrieved 12 August 2020 from www.waimakariri.govt.nz/__data/assets/pdf_file/0018/24138/Northern-Pegasus-Bay-Bylaw-2016.pdf.

Wallace, L. M., Hreinsdóttir, S., Ellis, S., Hamling, I., D'Anastasio, E., & Denys, P. (2018). Triggered Slow Slip and Afterslip on the Southern Hikurangi Subduction Zone Following the Kaikōura Earthquake. *Geophysical Research Letters, 45*(10), 4710-4718. doi:10.1002/2018GL077385

Weston, M. A., Dodge, F., Bunce, A., Nimmo, D. G., & Miller, K. K. (2012). Do temporary beach closures assist in the conservation of breeding shorebirds on recreational beaches? *Pacific conservation biology, 18*(1), 47. doi:10.1071/PC120047

Weston, M. A., Schlacher, T. A., & Lynn, D. (2014). Pro-environmental beach driving is uncommon and ineffective in reducing disturbance to beach-dwelling birds. *Environmental Management, 53*(5), 999-1004. doi:10.1007/s00267-014-0256-4

Whangarei District Council. (2009). *Control of Vehicles on Beaches Bylaw 2009*. Whangarei District Council. Retreieved 12 August 2020 from www.wdc.govt.nz/PlansPoliciesandBylaws/bylaws/Pages/VehiclesonBeachesBylaw.aspx.

Williams, J. R., Sim-Smith, C., & Paterson, C. (2013). *Review of factors affecting the abundance of toheroa (Paphies ventricosa). New Zealand Aquatic Environment and Biodiversity Report No. 114* Report prepared for the Ministry for Primary Industries. 80 pp.

Xu, W., Feng, G., Meng, L., Zhang, A., Ampuero, J. P., Bürgmann, R., & Fang, L. (2018). Transpressional Rupture Cascade of the 2016 Mw 7.8 Kaikoura Earthquake, New Zealand. *Journal of Geophysical Research: Solid Earth, 123*(3), 2396-2409. doi:10.1002/2017JB015168

Zharikov, Y., & Milton, D. A. (2009). Valuing coastal habitats: predicting high-tide roosts of non-breeding migratory shorebirds from landscape composition. *Emu - Austral Ornithology, 109*(2), 107-120. doi:10.1071/MU08017